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Mapping and Assessment of Ecosystems and their Services

Soil ecosystems

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List of abbreviations

Abbreviation	Explanation
ASD	Agenda for Sustainable Development
ATES	Aquifer Thermal Energy Storage
BISE	Biodiversity Information System for Europe
BTES	Borehole Thermal Energy Storage
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CICES	Common International Classification of Ecosystem Services
CIF	Common Implementation Framework
CORINE	Coordination of information on the environment
DG-ENV	Directorate-General for Environment
EAP	Environment Action Programme
EEA	European Environment Agency
ELD	The Economics of Land Degradation
ESS	Ecosystem Services
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GSP	Global Soil Partnership
id	international dollars
ITPS	Intergovernmental Technical Panel on Soils
JRC	Joint Research Centre
LDN	Land Degradation Neutrality
LUCAS	Land Use and Coverage Area frame Survey
LULUCF	Land Use, Land-Use Change and Forestry
MA	Millennium Ecosystem Assessment
MAES	Mapping and Assessment on Ecosystems and their Services
PETA	Pan-European Thermal Atlas
SDG	Sustainable Development Goal
SETIS	Strategic Energy Technologies Information System
SOER	The state of the environment
SOM	Soil Organic Matter
STS	Soil Thematic Strategy
SWSR	Status of the World’s Soil Resources
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEA	UN Environmental Assembly
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WG	Working Group

Executive summary

Soil ecosystem services, as all ecosystem services (ESS), are fundamental for meeting societal needs such as food and energy provision and for overcoming societal challenges like climate change mitigation and adaptation. The MAES (Mapping and Assessment on Ecosystems and their Services) Soil Pilot aims to increase awareness on the importance of soil functions and related ecosystem services and to show their value. The pilot shows the need for protection, management and restoration of soil ecosystems and the need to make a more sustainable and efficient use of it. In the context of the EU Biodiversity Strategy to 2020[1], the MAES Soil Pilot provides practical guidance and capacity building to the EU institutions and Member States on methods and tools for assessing soil ecosystem services.

The process of mapping and assessing soil ecosystems and their services starts with assessing ecosystem condition. Ecosystem condition determines the capacity of an ecosystem to yield services. Soil pressures influence the ecosystem condition and thus the potential to deliver services. Methods and data availability vary between ESS. Indicators for ecosystem condition are collected in MAES pilots for six ecosystem types: 1) Forest ecosystems, 2) Cropland and grassland ecosystems, 3) Freshwater ecosystems, 4) Marine ecosystems, 5) Urban ecosystems and 6) Soil ecosystems. The current report is developed in the context of the latter ecosystem.

This report provides the most comprehensive overview of soil ESS. All ESS included in this report meet the criteria of being goods or services that are provided by the ecosystem, used by humans, and contributing to human well-being. A number of the soil ESS are often not considered in general ESS assessments or in soil ESS assessments.

Structural analysis by policy makers and soil managers of the impact of their decisions on soil ESS will enable them to make better informed decisions. A good understanding of the contribution of soil ESS to human well-being will enable practitioners to develop soil management practices that stimulate the provision of multiple soil ESS. When analysing the impact of soil management practices on ESS, it is recommended to consider the entire list of soil ESS to prevent that less obvious aspects are overlooked. It is also important to consider the trade-offs between the potential supply, actual use and future demand of multiple soil ESS. The use of one service may result in reduced capacity of another service. Even when there is an indirect impact of changes in soil characteristics on ESS, the impact may be high. For example, temperature regulation by vegetation through transpiration may be severely impaired by a lack of available soil moisture.

There is no standard recipe for good soil management or land management. Since there are trade-offs between services, the optimal management depends on which ESS are demanded by society and on local soil characteristics that determine the potential for ESS. Information on the status of potential provision and demand for ESS can be used to prioritize management actions. Some practices impact many ESS or specific combinations of ESS as is demonstrated in this report. Policy makers could stimulate management practices that enforce multiple ecosystem services or mitigate adverse impacts on them. Still, priorities in soil management will always be determined by the demand for ESS and the subjective value that decision makers or the people that they represent assign to certain services. Enhancing the ESS delivered by the soil therefore starts with an integral assessment of current and future needs of humans, potential provision of ESS, and trade-offs between ESS. By comparing potential supply and use, it is possible to determine whether the use of soil is sustainable. Examples of this type of analysis from Flanders and the Netherlands are provided in this report. These examples demonstrate that many soil ESS are used unsustainably.

[1] COM(2011) 244 Our life insurance, our natural capital: an EU Biodiversity Strategy to 2020

The availability of indicators and data on soil ESS varies between services. For provisioning services, production and use are well documented. It requires further assessment to find out what causes the increase or decrease and what role is played by soil (condition). For example, agricultural outputs in Europe increased between 2000 and 2010 while at the same time, potential supply of these goods seems to decline based on available arable land and soil fertility. This may indicate unsustainable use of the crop production service and studies in Flanders and The Netherlands support this impression.

From the European studies that we considered, it is hard to determine if regulating services are improving or declining. One reason is that the role of soil is hidden in integrative indicators, soil being only part of the equation. Examples of integrative indicators are water retention capacity and relative water purification capacity of freshwater ecosystems. It would require more in-depth investigation to identify the role of soil in these indicators. However, the integrated indicators are valuable because they acknowledge the importance of an entire ecosystem, with all its components and processes, for provision of ESS. Extracting the role of soil may be useful for soil scientists and soil managers for the development of soil management practices that enable sustainable use of specific bundles of soil ESS.

Another difficulty with several regulating services is that their use is strongly spatially specific on a sometimes very local scale. For example, traffic noise reduction by bare soil and vegetation is provided at a level of spatial detail that is lost in assessments and maps at European scale.

The estimation of the economic value of soil ESS can inform decision-makers on soil use and management. However, the economic valuation of soil ecosystem services is still an emerging area of research where many gaps abound. Conceptually, there is no unified framework and most common approaches lag behind the developments in general economic valuation research. There are generally very few studies available, most of which focus on a handful of soil ESS and there are very few economic valuation studies of soil ESS conducted in Europe. Moreover, virtually all economic valuation studies of soil ESS focus on agricultural contexts. This means a huge lack of insight in the value of soil ESS in an urban context.

The available studies use very diverse, qualitatively divergent methods and approaches, which makes their results hardly comparable. Thus, economic valuation studies do not provide much information that can be informative for decision-making processes beyond the available biophysical data. This means there is significant potential for new research in this area. More focus on other contexts (e.g. urban soil ESS) and more research could improve the availability of information for decision makers in Europe.

1 Introduction

1.1 The importance of soil and its contribution to well-being and societal challenges

The delivery of ecosystem services is essential to fulfil societal needs (such as food, drinking water, energy production, infrastructure) and to overcome societal challenges (such as climate change mitigation and adaptation, migration, demographic growth). Soil is at the core of these challenges and the Europe 2020[2] challenges can only be met with sufficient and healthy land and soil. Soil provides goods and services that contribute to human wellbeing. In this report, we focus on the role of ESS as provided by soils.

Soil ESS can help achieving several of the Sustainable Development Goals (SDGs) of the United Nations (UN, 2015) as shown in Figure 1.1. For soil, SDG target 15.3 is most striking: “By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world” (see also Annex I).

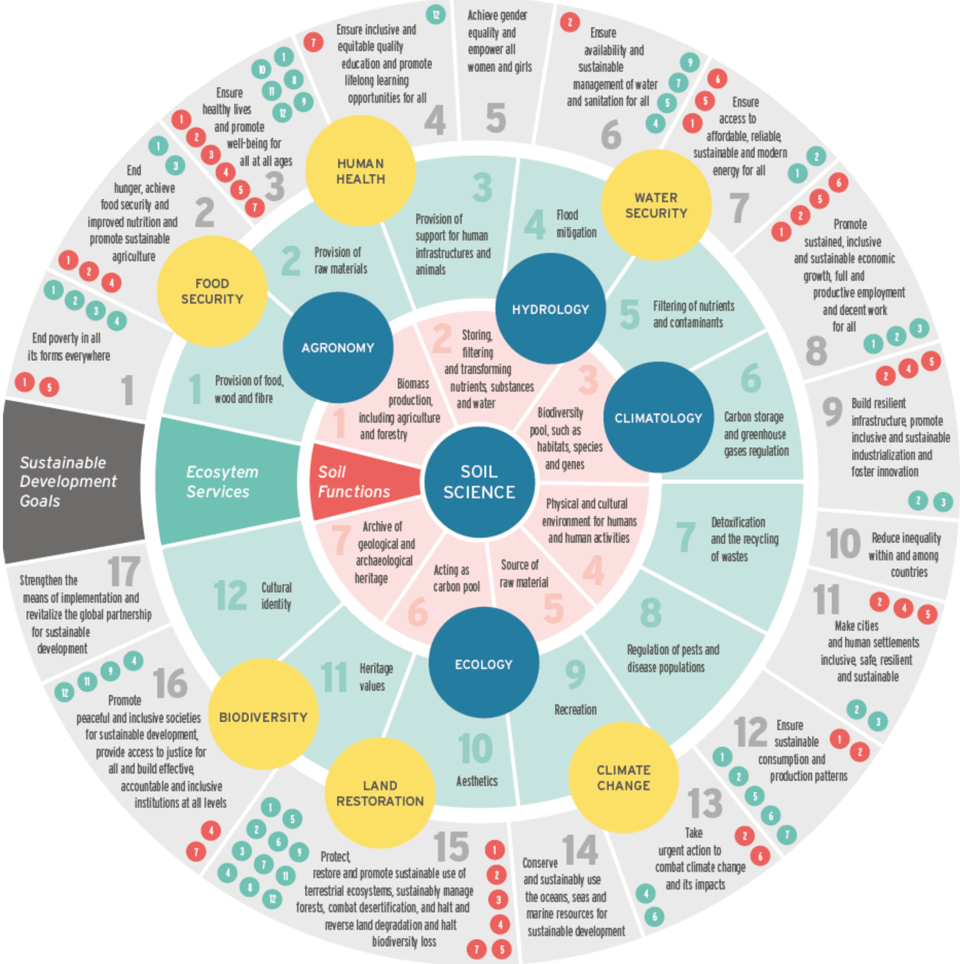

Figure 1.1: Soil functions support provision of ecosystem services that contribute to the achievement of multiple SDG’s as defined by the United Nations. Figure by Keesstra et al., 2016.

[2] COM(2010)2020, Europe 2020.: A strategy for smart, sustainable and inclusive growth.

Soil pressures
Availability of land and soil is under pressure. Land and soil are needed for multiple and competing uses, such as supporting houses, food and biomass production, biodiversity, water management, leisure and other cultural aspects. Soils in the EU are exposed to numerous pressures which limit their ability to deliver ESS. These threats include erosion, floods and landslides, loss of soil organic matter, salinisation, contamination, compaction, sealing, and loss of soil biodiversity. In its report on the state of the European environment, the European Environment Agency (EEA) stated that loss of soil functions and land degradation remain major concerns (EEA, 2015b). The scale of soil degradation in the EU is significant. Water and wind erosion affect approximately 22% of European land. 45% of the mineral soils in Europe have low or very low organic carbon content. Soil contamination affects up to three million sites and an estimated 32-36% of European subsoils are classified as having high or very high susceptibility to compaction (Jones et al. 2011). The EEA (2015b) also showed an increase in soil sealing, due to construction and infrastructure development. These soil pressures drive the loss of soil biodiversity. Due to accelerating drivers behind degradation such as increasing urbanisation, land abandonment, and intensification of agricultural production, soil degradation processes continue to undermine soil functions and the delivery of ESS (Frelih-Larsen et al., 2016).

The Seventh Environment Action Programme[3] recognises that soil degradation is a serious challenge. The following objectives are to be achieved by 2020:
- land is managed sustainably in the Union,
- soil is adequately protected, and
- the remediation of contaminated sites is well underway.

The 7th EAP wants the EU and its Member States to increase their efforts to reduce soil erosion, to improve the organic matter content in the soil as well as to remediate contaminated sites. In absence of EU legislation, soil protection is not subject to a comprehensive and coherent set of common rules in the Union. Existing EU policies in areas such as agriculture, water, waste, chemicals, and prevention of industrial pollution do contribute to the protection of soils. However, these policies alone are not sufficient to ensure an adequate level of protection for all soils in Europe. Some Member States developed specific national legislation on soils, but this is not the case for all countries in the EU.

Awareness on soil value
Soil is the foundation of all terrestrial ecosystems and the agricultural and forestry provisioning services, as well as being the structural medium for the terrestrial biosphere and human infrastructure. However, society is insufficiently aware of the role of these soil ESS. The risks and costs from the on-going degradation of ecosystems and their services are neither properly integrated into our economic and social systems nor into our decision-making processes (European Environment Agency, 2015a). This can lead to significant damage and loss of economic and societal benefits. Sustainable use of soils leads to value creation. To improve awareness and decision making in terms of sustainable use of soils, this value should be demonstrated. Some examples of the benefits of sustainably managed soils are provided below:
- Sustainable soil management ensures long-term yields. Balancing the organic matter content helps to achieve sound moisture content, a balance in leaching of nutrients and carbon sequestration, thus optimizing mitigation of climate change.
- Sustainable soil management in wetlands ensures the maintenance of the highest organic soil carbon density among terrestrial ecosystems, as well as the provision of water purification services;

[3] Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet' (OJ L 354, 28.12.2013, p. 171).

- Sustainable groundwater management can avoid soil subsidence and hence damage to (underground) infrastructure and prevent greenhouse gas emission. It can also contribute to climate change mitigation and adaptation and to nature conservation.
- Ensuring the optimal functioning of soil in urban areas by maximizing the presence of green infrastructure and limiting sealing, can help to buffer rain water thus contributing to climate change adaptation and avoiding costs for the over-dimension of sewer systems and for damage as a result of flooding.

There is quite a lot of scientific literature on soil functions, and since more recently also on soil ESS but the latter concept is still fairly unknown to soil stakeholders and policy makers. Shifting from a soil pressure approach towards a soil ecosystem services approach helps to promote the idea that soil can offer a valuable contribution to solve many societal challenges.

To further demonstrate and create awareness on the benefits of sustainable soil management in the context of different societal challenges, instruments such as ecosystem services mapping, monitoring and assessment need to be developed. It is therefore essential to clarify the concept: to identify the soil ESS, to elaborate an indicator framework to assess the soil condition, to identify both pressures and sustainable management practices that influence the ecosystem condition and to value soil ESS to enable policy makers and land users to integrate them in decision making.

Annex II contains a background paper “Towards societal benefits by soil services”, drafted by members of the MAES Soil pilot group after the Soil Stakeholders' Conference on 5th December 2016. With this background paper the MAES Soil pilot group aimed at: clarifying the concept of soil ESS and its added value for society; Exploring the links between soil services and societal challenges; Increasing awareness on the importance of well-functioning soil services; Connecting stakeholders; Starting a transition process towards more integrated and sustainable soil use and management.

1.2 EU Biodiversity Strategy, MAES and its soil pilot

1.2.1 EU Biodiversity Strategy to 2020 and MAES

The European Union adopted the Biodiversity Strategy[4] to halt biodiversity loss in the EU, restore ecosystems where possible and to step up efforts to avert global biodiversity loss. The strategy mirrors the global Aichi targets of the Convention on Biological Diversity[5] and builds further on a number of earlier measures including the Habitats Directive[6], the Birds Directive[7], The Water Framework Directive[8], the Marine Strategy Framework Directive[9] and the Air Quality Directive[10]. The Biodiversity Strategy has six targets and twenty supporting actions.

Target 2 of the EU Biodiversity Strategy aims to maintain and enhance ESS and to restore at least 15% of degraded ecosystems across the EU. To accomplish this, Action 5 foresees that Member States, with assistance of the European Commission, should map and assess the state of ecosystems and their services in their national territory, assess the economic value of such services and promote the integration of these values into accounting systems at EU and national level by 2020. To ensure the effective delivery of the EU Biodiversity Strategy to 2020 a Common Implementation Framework (CIF) was set up.

The Working Group on Mapping and Assessment on Ecosystems and their Services (MAES WG) established under the CIF is mandated to coordinate and oversee Action 5. In 2012, the Working Group developed ideas for a coherent analytical framework to be applied by the EU and its Member States to ensure that consistent approaches are used.

Following the adoption of the analytical framework, the MAES WG decided to test and further develop it by setting-up eight thematic pilots. Four of the pilots focus on the main ecosystem types: 1) agro-ecosystems (cropland and grassland), 2) forest ecosystems, 3) freshwater ecosystems (rivers, lakes, groundwater and wetlands) and 4) marine ecosystems (transitional waters and marine inlets, coastal ecosystems, the shelf, the open ocean as proposed in the MAES typology). The fifth and sixth pilot are relevant for all ecosystems. The fifth pilot on nature focused on the use of information reported in accordance with Article 17 of the Habitats Directive[11] and how this information can be used for the assessment of ecosystem condition. The sixth pilot explores the challenge of valuation and natural capital accounting. The idea to develop a specific MAES pilot on soil ecosystems and another one on urban ecosystems came at a later stage due to the cross-cutting dimension of those two pilots.

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[4] COM(2011) 244 Our life insurance, our natural capital: an EU Biodiversity Strategy to 2020

[5] https://www.cbd.int/sp/targets/

[6] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

[7] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds

[8] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

[9] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

[10] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

[11] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

1.2.2 Ambition of the MAES Soil pilot

The ambitions of the MAES Soil Pilot are to:

1. Increase awareness of the importance of soil functions and related ESS, showing their value for society, the need for protecting, managing and if needed restoring this value, and make a more sustainable use of our natural capital, according to the principle of 'planetary boundaries' taking account of future generations;
2. Provide an indicator framework and working guidance to the EU institutions and Member States on methods and tools for mapping and assessing soil ESS;
3. Build capacity: it is an opportunity for exchanging experiences and involving stakeholders. This implies communicating on success but also fail factors at EU, national, regional and local level;
4. Be policy-oriented, providing a realistic method for soil ESS assessment, with direct integration potential e.g. in Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), environmental compensation discussions, land use planning, monitoring of land take limitation and mitigation measures and land degradation neutrality, soil protection policy, etc.;
5. Enable an improvement of the knowledge base, through the building of a shared assessment framework connecting EU, national, regional and local interests and decisions;
6. Support EU policy frameworks that are expected to directly benefit from this pilot project, including the EU Biodiversity Strategy to 2020[12], the Soil Thematic Strategy[13], the 7th Environment Action Programme 2014-2020[14], Common Agricultural Policy (CAP), Forest Strategy[15], disaster prevention, climate change policies, etc..

More backgrounds about European and international soil-related policy can be found in Annex I.

[12] COM(2011) 244 Our life insurance, our natural capital: an EU Biodiversity Strategy to 2020

[13] COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection

[14] Decision No. 1386/2013/EU of the European Parliament and of the Council on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'

[15] COM(1998) 649, 03/11/1998 Communication from the Commission on a Forest Strategy for the European Union

2 Terminology and concepts

2.1. Definition and classification of Ecosystem Services

The Millennium Ecosystem Assessment (MA, 2005) defines ecosystem services as "the benefits that people obtain from ecosystems". The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010) defines ESS as "the direct and indirect contributions of ecosystems to human well-being". In order to be more concrete about these contributions we extend this definition to "the goods and services provided by ecosystems that directly and indirectly contribute to human well-being". These last words refer to the essential aspect of the ESS concept, that it is an anthropocentric approach.

For this report, we use the Common International Classification of Ecosystem Services (CICES)[16] since it is state of the art and broadly used in the EU. CICES aims to support economic analysis. It includes three categories of ESS (Haines-Young and Potschin, 2016):

- **Provisioning services**
  These are the material and energetic outputs from ecosystems from which goods and products are derived.
    - Example: ground- and subsurface water for drinking
- **Regulation & maintenance services**
  This category refers to the ways in which ecosystems can mediate the environment in which people live or depend on, and benefit from them.
    - Example: pest control
- **Cultural services**
  This encompasses all the immaterial characteristics of ecosystems that contribute to, or are important for people's mental or intellectual well-being.
    - Example: characteristics of nature that enable education and training

Some classification systems, like the MA , also include **supporting services**, such as soil formation or nutrient cycling. These support the provision of other services, but are excluded from CICES. Supporting services are only indirectly consumed or used and in CICES treated as part of the underlying structures, processes and functions that characterise ecosystems.

For the analysis of changes in ESS, this report provides information on two aspects: the potential of the soil to provide ESS and the actual use, also called the flow, of ESS by humans. This use leads to benefits such as contribution to human health and welfare (Figure 2.1).

[16] The European Environment Agency (EEA) commissioned the development of the Common International Classification of Ecosystem Services (CICES) to support environmental accounting according to the System of Environmental-Economic Accounting (SEEA) led by the United Nations Statistical Division (UNSD). This classification system builds on the Millennium Ecosystem Assessment (MA, 2005) and TEEB. See: cices.eu V5.1.

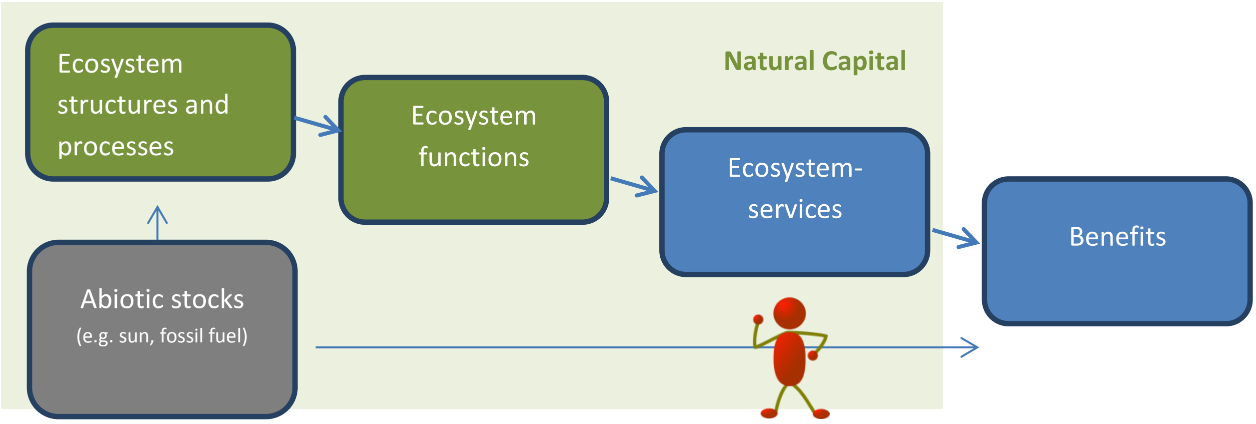


Figure 2.1: Figure based on the cascade model (Potschin and Haines-Young, 2011); the natural capital model (Petersen & Gocheva, 2015) and Van der Meulen et al., 2016.

2.2 Soil functions and soil ecosystem services

Soil ESS are ecosystem services that depend on the functional processes and properties of the soil. Soil is generally defined as the top layer of the earth's crust, formed by mineral particles, organic matter, water, air and living organisms. It is the interface between earth, air and water and hosts most of the biosphere[17].

A clear distinction is made between ecosystem functions and ecosystem services. Ecosystem functions are the ecological processes that result in the supply of ecosystem services. In the MAES conceptual framework, ecosystem services are the benefits that people obtain from ecosystems, either directly or indirectly. The service flow in this framework refers to the actually used service (Maes et al. 2013). Changes in ecosystem functions influence the potential supply of ecosystem services.

In a communication from the Food and Agriculture Organization (FAO) about the importance of soil for life on earth (FAO, 2015). The FAO described eleven 'soil functions' or 'ecosystem services' (Figure 2.2):

[17] Definition from the Soil Thematic Strategy. COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection

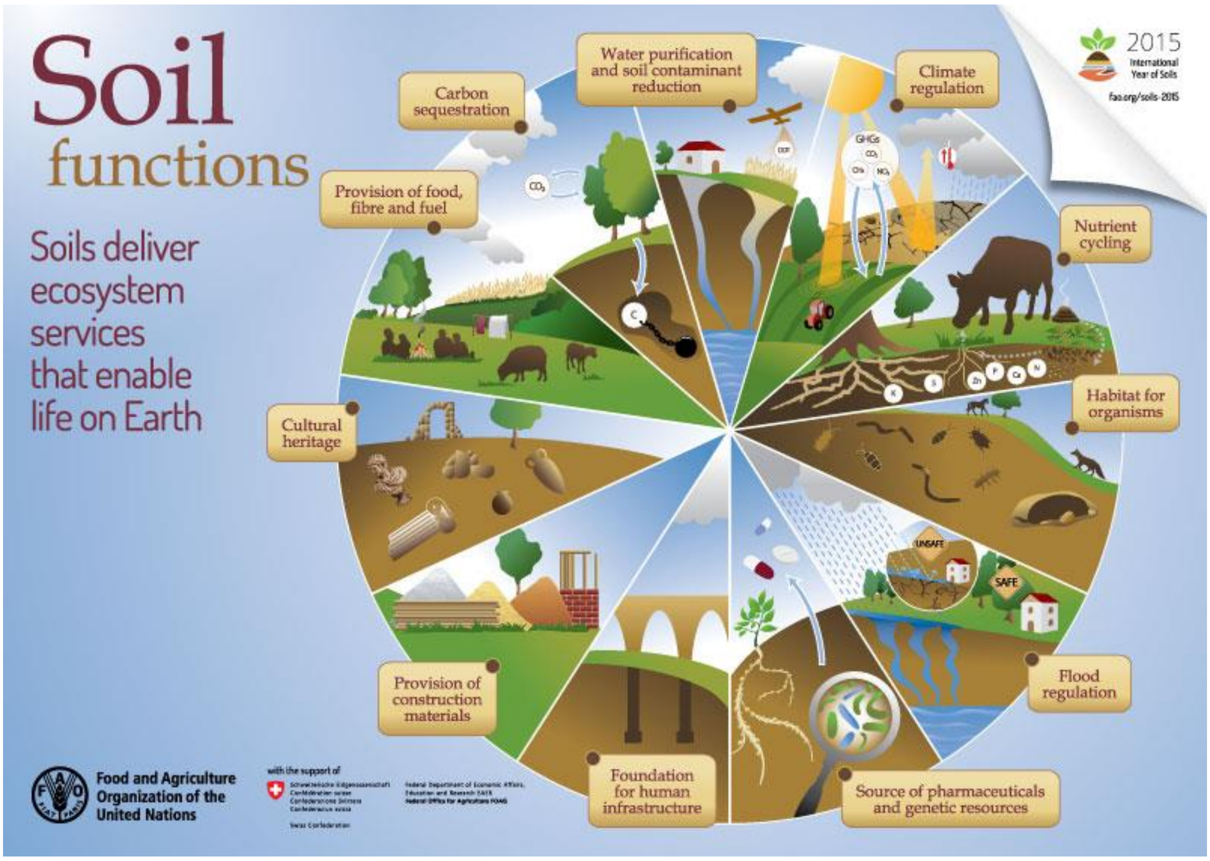


Figure 2.2: Soil contributes to ecosystem services, also called 'soil functions' by FAO, that are crucial for human well-being (FAO, 2015).

2.3 MAES conceptual framework

The process of mapping and assessing ecosystems and their services following the MAES-framework is summarized in this section. The in-depth report 'Ecosystem Services and Biodiversity' (Science for Environment Policy, 2015) describes the process more in detail.

The MAES process starts with mapping ecosystems. It is suggested to use large-scale land cover maps such as CORINE Land Cover, linking land cover to ecosystems, the European Nature Information System (EUNIS) classification and data on elevation, or geological conditions. A map of European ecosystem types can be found on the website of the Biodiversity Information System for Europe (BISE).[18]

The second step is to assess the ecosystem condition: the physical, chemical and biological quality of the ecosystem. Ecosystem condition determines the capacity of an ecosystem to yield services (Maes et al., 2014; EEA, 2015a). The Joint Research Centre (JRC) specified the relation between ecosystem condition and the provision of soil ESS. Figure 2.3 shows how ecosystem condition affects the provision of ecosystem services. It also shows that soil pressures influence ecosystem condition.

[18] https://biodiversity.europa.eu/maes/mapping-ecosystems/map-of-european-ecosystem-types

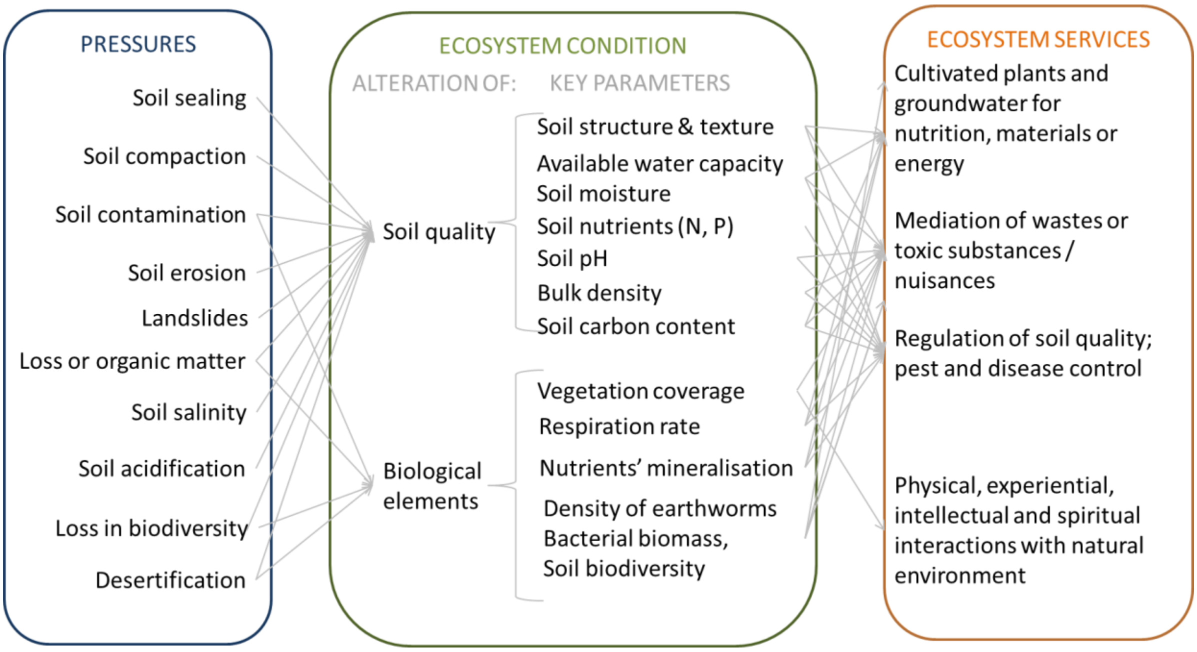


Figure 2.3: This figure explains how the delivery of soil ecosystem services depends on ecosystem condition, which in turn is influenced by soil pressures (Developed by JRC's MAES Soil working group, 2017)

3 Soil ecosystem services

3.1 Overview of soil ecosystem services

Table 3.1 provides an overview of soil ESS and the terminology used to describe them. When cited documents use a different terminology for the same ESS, the original phrasing is also given, in square brackets [].

Some classification systems, like the Millennium Ecosystem Assessment, also include supporting services. Services supporting the provision of other services are excluded from CICES, e.g. 'recycling of organic matter into nutrients' and 'base of all terrestrial ecosystems/life and biodiversity support'.

In table 3.1 the CICES **Section**[19] is used as a header to group the ecosystem services. The table is organized as followed:

- In the first column the **soil ecosystem service** is described. The 1 or 2 behind the ecosystem service indicates respectively whether it is a primary (direct) or secondary (indirect) soil ecosystem service.
- In the second column the CICES **Class**[20] is mentioned (due to a lack of space the CICES Division[21] and Group[22] are not stated).
- The third column gives the CICES **Class type**[23].
- In the fourth column **examples** are given.
- The fifth column mentions the **functional processes and properties** that provide the ecosystem.
- In the last column, the **sources** from which the information in this table is derived are given.

[19] CICES Section lists the three main (biotic and abiotic) categories of ecosystem services: Provisioning services; Regulating and maintenance services and cultural services.
[20] The CICES class level provides a further sub-division of group categories into biological or material outputs and bio-physical and cultural processes that can be linked back to concrete identifiable service sources.
[21] The CICES Division divides section categories into main types of output or process. (such as nutrition, materials, …)
[22] The CICES group level splits division categories by biological, physical or cultural type or process. (such as biomass, water)
[23] The CICES class types break the class categories into further individual entities and suggest ways of measuring the associated ecosystem service output. (such as Crops by amount, type)

Table 3.1: Examples of soil ecosystem services, the functional processes that are required to provide the services and contributing and limiting factors. Table based on MAES Soil pilot, Dominati (2010), Adhikari and Hartemink (2016) and linked to the CICES (5.1) categories.

Ecosystem Service	CICES class	CICES class type	Examples	Functional process(es) + properties	Source info
Provisioning services					
Biochemical and pharmaceuticals (1)	*No class provided in CICES (CICES division Materials)*	*No class type provided in CICES*	Penicillin is a soil bacteria.	Biodiverse soil biota could be a source of new pharmaceuticals.	MAES soil pilot, Adhikari and Hartemink (2016), Jeffery et al., 2010.
Food, wood and fibre (1)	Cultivated terrestrial plants (incl. fungi, algae) grown for nutritional purposes or as a source of energy; Fibres and other materials from cultivated pants fungi, algae and bacteria for direct use or processing.	Crops by amount, type	Crops by amount, type, source; material by amount, type, use, media (land, soil)	Structure, water holding capacity and nutrients fertility.	Dominati, 2010, Adhikari and Hartemink, 2016
Fresh water (1)	Ground (and subsurface) water for drinking or non-drinking purposes	By amount, type, source	Groundwater as resource for irrigation, drinking water or non-drinking water purposes	Texture, structure, water holding capacity, depth, subsoil pans	Adhikari and Hartemink, 2016 (some properties bundled)
Carrying capacity for infrastructure, buildings and animals [support of animals and infrastructure][carrier function] (1)	*No class provided in CICES*	*No class type provided in CICES*	Peat soil has a low carrying capacity compared to e.g. sand	Soil texture, structure, moisture content	Hopman et al, 2013; Dominati et al., 2010; De Groot, 2006; Brady and Weil, 1999
Raw materials (1)	Mineral substances used for nutritional or material purposes or as energy source	Amount by type	Peat for fuel and clay for potting	Sedimentation, weathering, erosion	Dominati, 2010, Adhikari and Hartemink, 2016.
Thermal energy (1)	Ground water (and subsurface) used as an energy source; Geothermal	By amount & source, amount by type	Shallow geothermal energy storage and extraction, e.g.: Aquifer thermal energy storage (ATES) and borehole thermal energy storage (BTES); direct use of hot water or steam for heating; higher temperature storage (HTS)	Texture, temperature conductivity, depth and thickness of aquifer, groundwater flow, quality of the groundwater (presence of pollutants, salinity)	Paksoy et al., s.a. Hoekstra et al. 2015 SETIS[24]

[24] SETIS. https://setis.ec.europa.eu/setis-reports/setis-magazine/geothermal-energy/regeeocities-promoting-shallow-geothermal-resource. Visited April 2017

Ecosystem Service	CICES class	CICES class type	Examples	Functional process(es) + properties	Source info
Regulation and maintenance services					
Water purification and soil contamination reduction (1)	Bio-remediation by micro-organisms, algae, plants, and animals; Filtration/sequestration/storage/ accumulation by micro-organisms, algae, plants, and animals; Mediation of waste toxics and other nuisances by non-living processes	By type of living system or by waste or substance type; amount by type	Atmospheric deposits, applied fertilizers, pesticides or other contaminants are adsorbed into soil aggregates, by clay particles and organic matter, and degraded (chemically altered) by soil biota which metabolize contaminants through oxidative or reductive processes	Soil texture, structure, organic matter content, biodiversity of soil biota. Micro-organisms require nutrients, moisture and appropriate pH (5.5-8.5, best at 7.0) and temperature (15-45°C), plus specific redox conditions. Processes will not proceed if too many inhibiting or toxic compounds are present.	MAES soil pilot, Adhikari and Hartemink, 2016
Water regulation (1)	Hydrological cycle and water flow regulation (including flood control and coastal protection);	By depth/volumes	Mitigation of floods, groundwater recharge	Soil texture, structure, organic matter content, depth, water holding capacity, subsoil pans.	MAES soil pilot, Adhikari and Hartemink, 2016
Biological control of pests and diseases (2)	Pest control (including invasive species); Disease control	By reduction in incidence, risk, area protected	By reduction of incidence, risk, area protected by type of living system	Soil moisture content, organic carbon content, pH, temperature determine which biota can be present.	Dominati, 2010, Adhikari and Hartemink, 2016
Carbon Sequestration (1)	Weathering processes and Decomposition and fixing processes and their effect on soil quality	By amount/ concentration and source	Carbon in short-lived to more stable forms of soil organic matter (SOM) is stored (and recycled).	Soil texture, structure, moisture regime, nutrient regime (e.g. N availability), temperature, level of biotic activity, associated vegetation and soil disturbance regime.	MAES pilot, Adhikari and Hartemink, 2016

Ecosystem Service	CICES class	CICES class type	Examples	Functional process(es) + properties	Source info
Regulation and maintenance services					
Regulation of greenhouse gasses (1)	Regulation of chemical composition of atmosphere and oceans	By contribution of type of living system to amount, concentration and climatic parameter	Soil biota affect fluxes of CO_2, CH_4 and N_2O.	Soil texture, Soil moisture regime, water holding capacity, nutrients (organic matter), temperature, microbial activity levels.	MAES pilot, Adhikari and Hartemink, 2016
Regulation of local climate/temperature (2)	Regulation of temperature and humidity, including ventilation and transpiration	By contribution of type of living system to amount, concentration and climatic parameter	Soil provides a habitat to vegetation that provides shading and cooling through evapotranspiration. Perceived thermal comfort may also be higher in a green environment.	Structure, water holding capacity and nutrients fertility. Water availability is of special importance for transpiration.	Bowler et al., 2010, Steeneveld et al., 2011, Van Hove et al., 2015, Heusinkveld et al., 2014 Klemm et al., 2014, Van der Meulen et al., 2015
Noise abatement (2)	Noise attenuation	By type of living system	Adsorption of noise by open soil, and soil also provides a substrate for vegetation that can reduce noise.	Structure, water holding capacity and nutrients fertility.	Derkzen et al., 2015, Van Rentherghem, 2014, EEA , 2016a
Air quality regulation (2)	Filtration/sequestration/storage/ accumulation by micro-organisms, algae, plants, and animals; Mediation of waste toxics and other nuisances by non-living processes	By type of living system or by water or substance type; amount by type	Soil provides a habitat to vegetation that influences air quality.	Structure, water holding capacity and nutrients fertility (for vegetation; soil properties strongly influencing effect of bare soil on noise not found).	Nowak et al., 2006; Pugh et al., 2012; Vos et al., 2013, EEA, 2016a

Ecosystem Service	CICES class	CICES class type	Examples	Functional process(es) + properties	Source info
			Cultural services		
Recreation and tourism (2)	Characteristics of living systems that enable activities promoting health recuperation or enjoyment through active or immersive interactions; or through passive or observational interactions; natural abiotic characteristics of nature that enable active or passive and experiential interactions	By type of living system or environmental setting; amount by type	Recreation on campsites, specific landscapes such as dunes or mountains, gardening, children playing in garden.	All soil properties as they relate to human health and comfort for use (e.g ponding due to unfavourable hydrological conditions reduces usability for recreation): Soil chemical quality texture, moisture, organic carbon, bulk density, structure & aggregation	Marion and Cole, 1996; Paracchini et al 2014; Dominati et al. 2010; Adhikari and Hartemink 2016, EEA, 2016a, Comerford et al., 2013
Knowledge/scientific research, Cultural heritage and education (1)	Characteristics of living systems that: enable scientific investigation or the creation of traditional ecological knowledge; enable education and training; are resonant in terms of culture or heritage; enable aesthetic experiences; natural abiotic characteristics of nature that enable intellectual interactions.	By type of living system or environmental setting; amount by type	Archaeology and other research (e.g. historic climate change), geological heritage.	All soil without buildings on top are suitable for research. Preservation potential is influenced by soil type and hydrological conditions.	Nahuelhual et al., 2014, Tengberg et al. 2012, Adhikari and Hartemink, 2016, Comerford et al., 2013, EEA, 2016a. Kibblewhite et al., 2015.
Spiritual and symbolic experience (2)	Elements of living systems: that have symbolic, sacred or religious meaning; used for entertainment or representation; natural abiotic characteristics or features of nature that enable spiritual, symbolic and other interactions.	By type of living system or environmental setting; amount by type	Landscape-specific locations such as battlefields, ceremonial sites, and cemeteries.	-	-

3.2 Quantification of soil ecosystem services

This section describes the status (potential and actual use, or flow) of soil ecosystem services identified in table 3.1 in Europe.

3.2.1 Potential and use of provisioning services

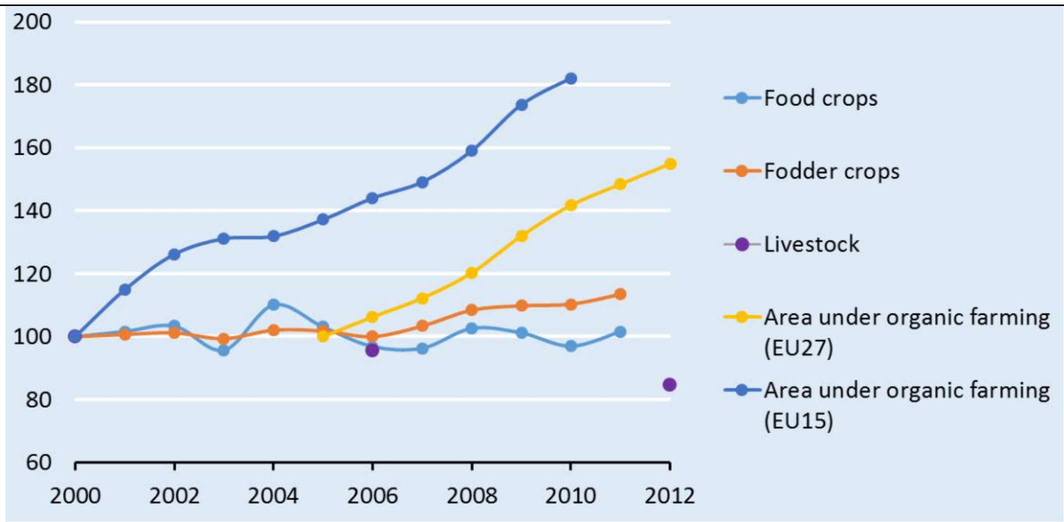
Biochemicals and pharmaceuticals

Soils are a source of biochemicals and pharmaceuticals. For example, Ling et al. (2015) found a new antibiotic from a soil bacterium present in grassland. For the provision of biochemicals and pharmaceuticals, Maes et al., 2014, report ‘raw materials for medicines’ as indicator in forest ecosystems. European data for potential and use, as well as the role of soil, specifically for biochemicals and pharmaceuticals could not be found.

Food, wood and fibre

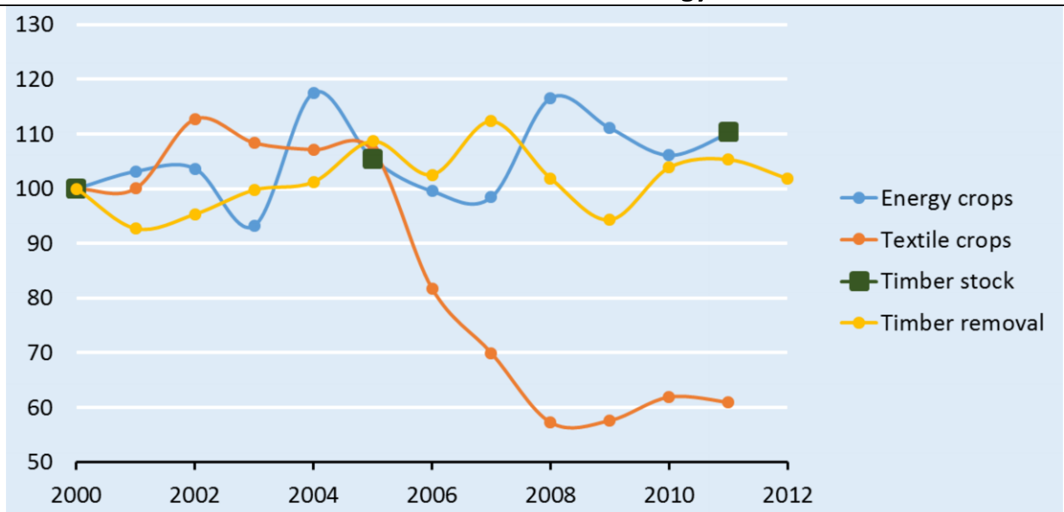
One of the most important soil ecosystem services is the provision of food crops and other biomass such as wood and textile crops. In the EU, the largest harvest in tons is related to fodder products. Between 2000 and 2011, the area of agricultural land decreased by 2.1 % while production increased (Figure 3.1, Maes et al., 2015b), suggesting an increasing pressure on land and soil. In Maes et al. (2015b), the surface area of organic crops is presented as an indicator for the supply of the service. In order to assess the sustainability of agricultural production, comparison with soil fertility and soil quality data would be relevant in future projects. Different studies (e.g. for Western Europe: Stoate et al., 2009, Virto et al., 2015) show that soil is under pressure due to intensification of production

Food and fodder



Food and fodder crop production increased, even when agricultural area decreased,, More organic food is grown. Numbers of livestock decreased.

Materials timber and energy



Afforestation in Europe resulted in increasing timber stocks and higher removals. Energy crops fluctuated while textile crops slashed

Figure 3.1: Harvest in the EU with 2000 as reference year. (Maes et al., 2015b)

Figure 3.2 shows the spatial differences in the production of specific crop types in Europe (Maes et al., 2015b). The highest food crop production per hectare (in 2010) is found in the Netherlands and Belgium. Fodder production was strongest in the UK and Ireland. Energy crops harvest was highest in Denmark, UK, Germany, France and Hungary. Timber removal volumes were high in many countries in the north and central European regions and some areas in France and Portugal. The total harvested production decreased between 2000 and 2010 in Cyprus, Greece, Italy, France and Estonia.

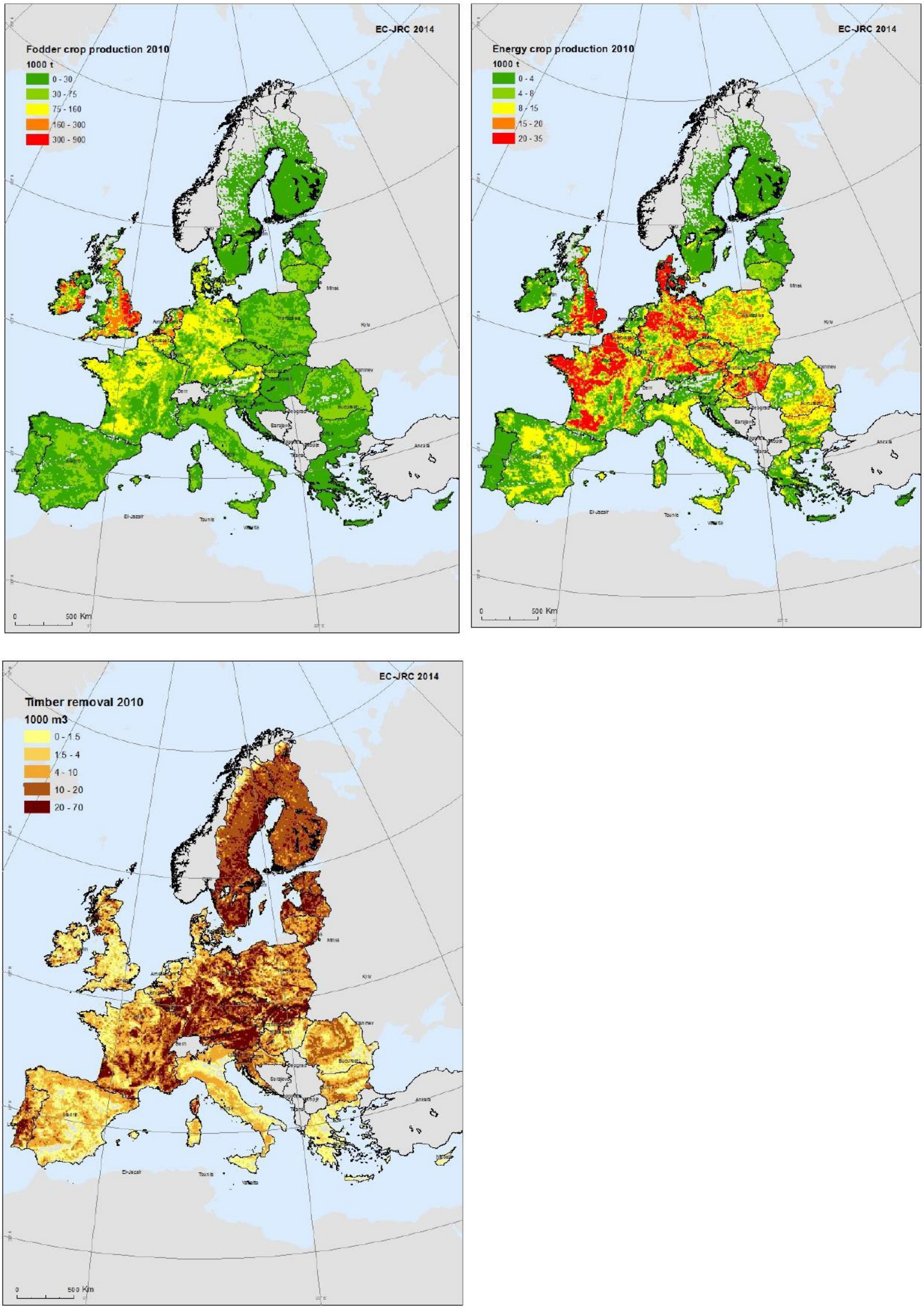
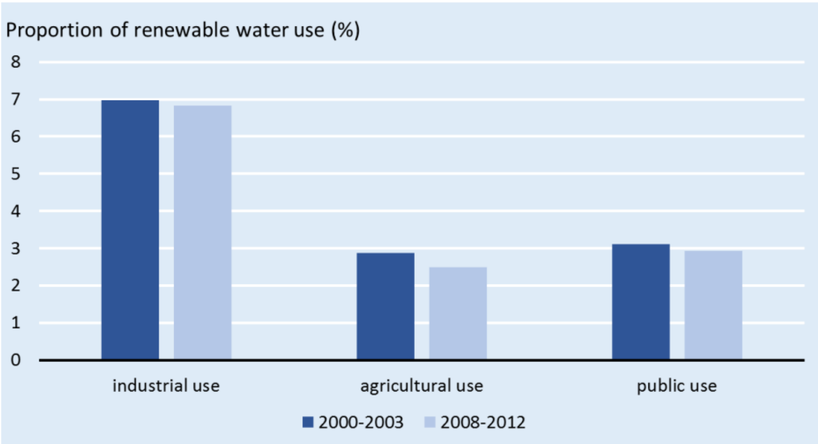


Figure 3.2: Production of specific crop types in Europe in 2010 (Maes et al., 2015b)

Fresh water

Fresh water (both surface water and groundwater) is used for industrial, agricultural and public use (drinking water). The provision, regulation and purification of water are very important soil ecosystem services that safeguard water quality and availability (Maes et al., 2011). The water retention index (dimensionless, between 0-10) is an indicator for the water regulation potential (Maes et al., 2015b). The index takes the role of soil for water retention into account, together with interception by vegetation and relative capacity of both soil and bedrock to allow percolation of water. The influence of soil sealing and slope gradient are additionally considered. Water retention capacity remained almost equal between 2000 and 2010 with an increase of the index from 4.039 to 4.046. Fresh water abstractions for industry, agriculture and public water use decreased by 5.6% between 2000 and 2010, from 195 billion m^3 per year to 184 billion m^3 per year. Figure 3.3 shows the water abstraction per sector as percentage of to the total available volume of renewable freshwater resources. In the period 2008-2012, 6.8% of renewable freshwater was used for industrial applications. Agriculture accounted for 2.5% while public withdrawals equalled 3%. In Maes et al. (2015b), no distinction is made between surface water and groundwater.



Data source:

Aquastat (FAO).
Data for 3 regions in the UK are estimated

Figure 3.3: Water abstraction in the EU per sector as percentage of to the total available volume of renewable freshwater resources (Maes et al., 2015b).

A global assessment on groundwater stress in the period 1990-2010 outside mountainous areas shows that for large parts of Europe, no groundwater stress is identified based on model calculation (Faneca Sànchez et al., 2016)[25]. However, even in low lying areas such as the Netherlands, groundwater stress does occur. In areas that suffer from groundwater stress, the potential delivery of groundwater is not high enough to meet the demand. Groundwater stress in Figure 3.4 is based on groundwater recharge and groundwater abstraction. The model simulates abstractions based on the availability and water demand for different sectors. It does not account for groundwater quality even though for many uses, chemical pollution or salinisation reduces the suitability of groundwater for uses like irrigation or drinking water. The global water model is described in Wada et al., 2014.

[25] The map is also included in Aqueduct Water Risk Atlas that is developed and hosted by the World Resources Institute (WRI).

Blue: no groundwater stress;
Light blue: low groundwater stress;
Light yellow: medium to high stress.
Yellow: high groundwater stress,
Red: extremely high groundwater stress,
White: excluded (mountainous areas or oceans/big lakes)

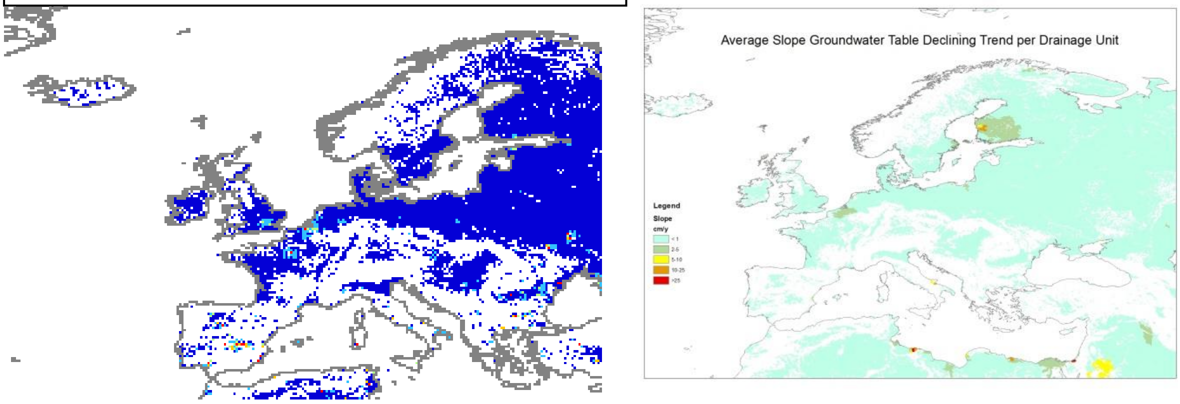


Figure 3.4: Left: Groundwater stress as an average 1990 to 2010. Right: Extent of groundwater table decline: more than 2 cm per year in a few areas in Europe (Faneca Sànchez et al., 2016)

Carrying capacity
Soil provides physical carrying capacity for infrastructure, buildings and animals. Soil properties like structure, texture and geohydrological conditions influence this service. Peat and clay soils have a relative low carrying capacity and are prone to subsidence while sandy soils provides firm foundation for infrastructure. Sand layers underlying peat or clay can be used to support pile foundation for buildings and infrastructure. No European data are available, but regional or national data may be used at the local level. For example, the Netherlands included maps on this aspect in the national Atlas Natural Capital[26] (information not available in English).

Raw materials
For this ecosystem service, Tóth et al. (2013) provided a map (Figure 3.5) of the availability of raw material from soils in the European Union. A distinction is made between organic soil material, based on all organic soils (histosols) and soil material for construction, based on presence of sand and gravel. Although loamy clay is often used for the production of bricks and tiles, it is excluded from the analysis because the currently available continental soil databases do not contain information on soil texture at this level of detail. There is no EU-wide data on potential or actual flow.

[26] http://www.atlasnatuurlijkkapitaal.nl/kaarten (information not available in English).

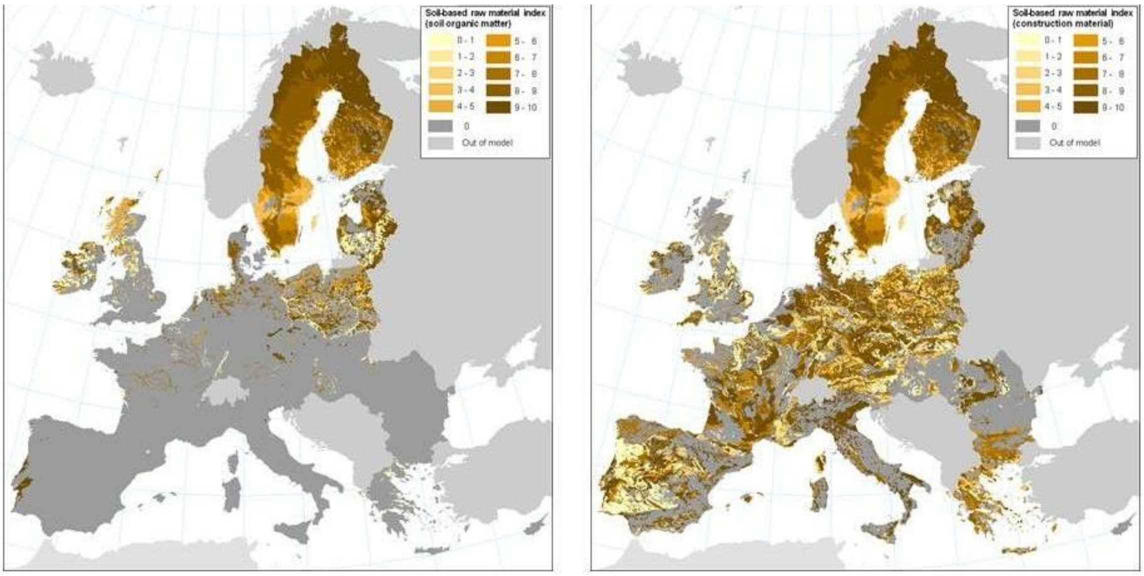


Figure 3.5: Map indicating the availability of raw material from soils in the European Union (Tóth et al., 2013). Left: organic soil material. Right: soil material for construction.

Thermal energy storage and extraction

In an Aquifer Thermal Energy Storage (ATES) system, cold water is stored in the aquifer during winter to be used in summer to cool buildings; warm water is stored in summer and being used in winter. In a Borehole Thermal Energy Storage (BTES) system, water is being circulated through a closed system of subsurface pipes. During summer, water from the building is cooled down in the subsurface and in winter, water is being heated by the relative warmer subsurface. Warm water in an ATES system is usually not warmer than 25 to 30 degrees. Residual heat from solar systems or deep geothermal heat, often 40 to 80 degrees, can also be stored in the subsurface to prevent energy loss during conversion with heat pumps (Hoekstra et al., 2015). Hoekstra et al., based on literature and field research, assessed the potential for ATES in Europe (Figure 3.6). The differences between regions are the result of differences in (geo)hydrological properties.

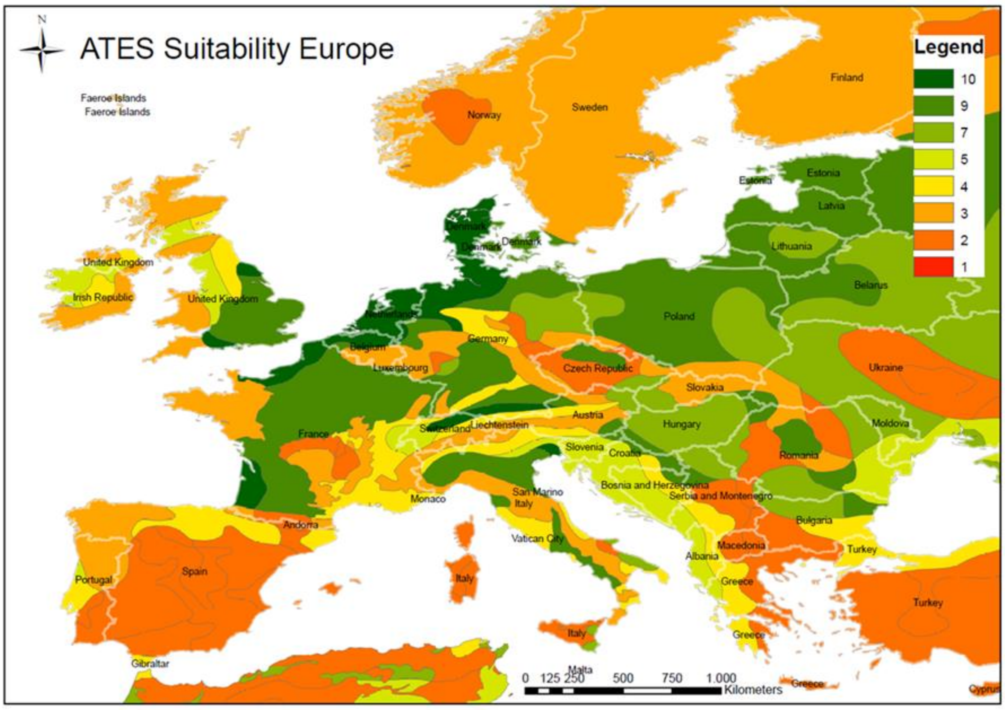


Figure 3.6: Potential for ATES in Europe; differences between regions are the result of differences in (geo)hydrological properties (Hoekstra et al., 2015).

Next to the potential supply of thermal energy storage, the demand for heating and cooling defines whether ATES could offer a potential solution. Areas with a moderate sea or land climate are expected to have highest demand. Figure 3.7 shows where both heating and cooling are expected to be needed mostly, based on climate types (Hoekstra et al., 2015). Another important aspect that determines demand is the presence of urban areas, where most buildings to be heated and cooled are located. In some regions, the presence of greenhouses may increase the demand for heating.

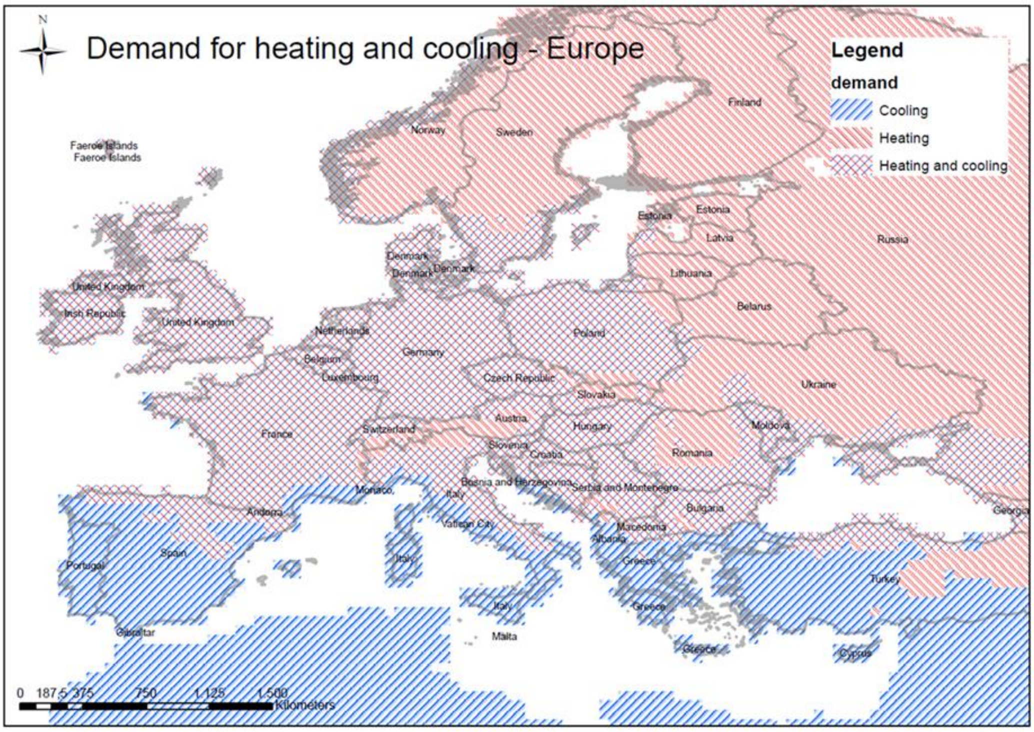


Figure 3.7: Demand for heating and cooling based on climate types (Hoekstra et al., 2015).

3.2.2 Potential and use of regulation and maintenance services

Water purification and soil contamination reduction

Soil contributes to the purification of water through physical, chemical and biological processes that result in immobilisation, degradation and dilution of substances. The potential provision of this service depends on soil properties and on the specific characteristics of the substances. Examples of direct use of this service are infiltration of water in riverbanks or dunes as part of the treatment process for drinking water production. There a no EU-wide data on potential or actual flow of this ESS.

In the soil naturally present bacteria degrade contamination. This ability of soil to degrade contamination can be used as (part of) a remediation strategy: natural attenuation of contaminants. This can be stimulated by optimizing the conditions for biological degradation. To stimulate the degradation process, an electron donor or acceptor can be added to the soil. If there is a shortage of nutrients or if the required bacteria are not in sufficient numbers present they are also added[27].

[27] https://soilpedia.nl/soilection/en/archivetechniques/

Water regulation
Soil is an important part in the hydrological cycle. Water regulation is influenced by soil properties such as soil texture, structure, organic matter content, groundwater depth, water holding capacity and subsoil stratification. Soil slope and vegetation are also relevant. Together these soil properties determine rainfall infiltration and the rates of surface run-off. Thereby, this determines groundwater recharge, peak flows, flood risk, rates of erosion and sediment load in flood waters. European data are not available, but regional or national data may be used at the local level.

Pest and disease control
Soil microorganisms play an important role in plant disease control. In general, total microbial biomass and high biodiversity create unfavourable conditions for plant species. Antagonistic microorganisms are used in seed and soil treatment products for a variety of applications against soil-borne crop diseases (Jeffery at al., 2010). No European maps on biological control of pests and diseases or soil biodiversity are available. The European map of threats to soil biodiversity (Figure 3.9) may be relevant to assess future changes in soil biodiversity. This could be used as indicator for pest and disease control soil ESS. The threat was determined by a combination of factors, such as pressures (such as intensive exploitation) exerted on soil, and the soil use (arable soils are the most exposed to pressures). The map shows the highest potential threats to soil biodiversity in north-western Europe.

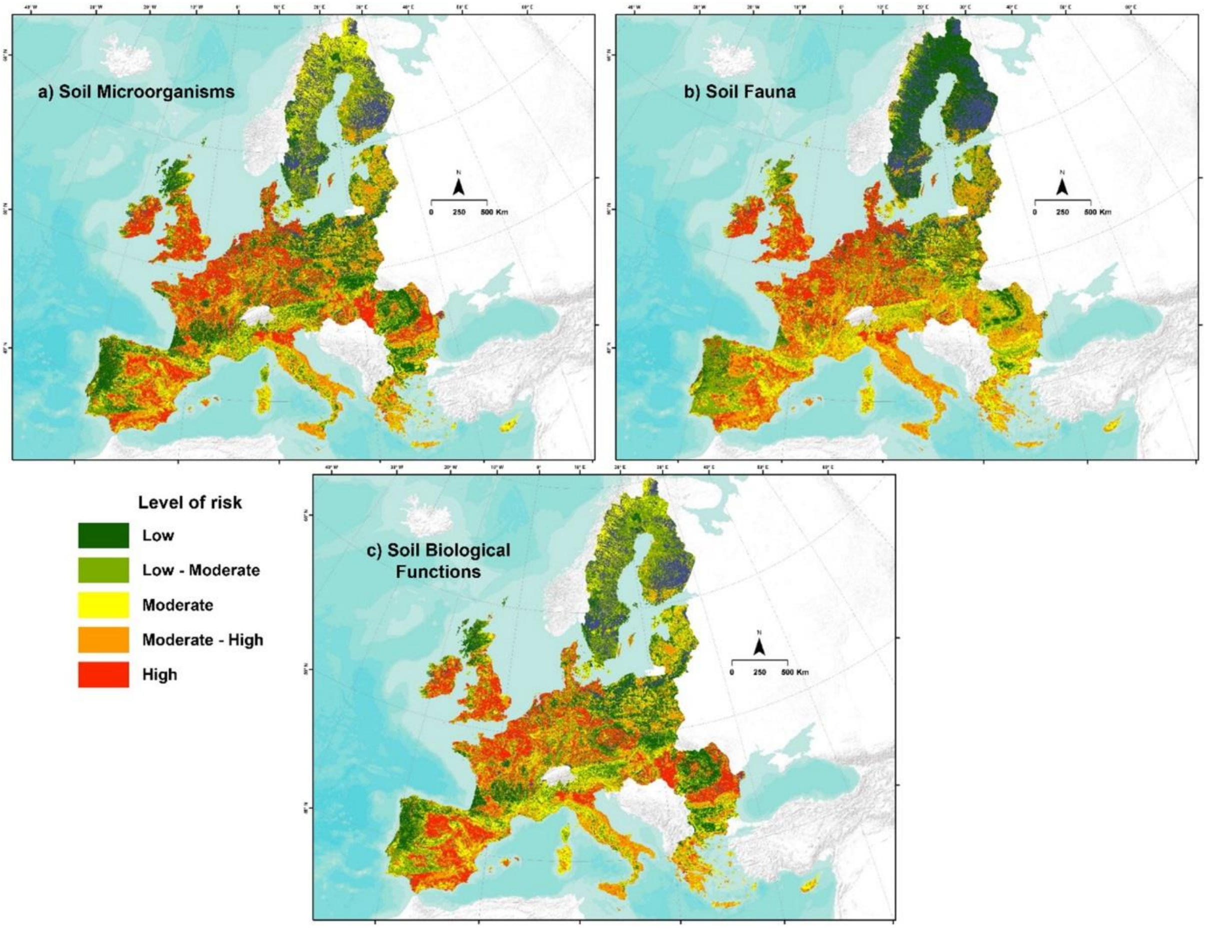


Figure 3.9: Maps showing potential threats to soil biodiversity in Europe (for soil microorganisms, for fauna, for biological functions) in Europe (Orgiazzi et al., 2016)

Carbon sequestration and regulation of greenhouse gasses
Soil plays a role in regulating global climate through the nutrient cycle which includes uptake of carbon from the atmosphere and subsequent storage and emission of greenhouse gasses. Carbon sequestration is often used as an indicator for this service. The total carbon stock per hectare in the EU ranged from 0-11 to 60-116 tons in 2000 (see map in Figure 3.10, Maes et al., 2011).

The map in Figure 3.11 shows the Soil Organic Carbon (SOC) saturation capacity, expressed as the ratio between the actual and the potential SOC stock in each pixel. Values close to 0 indicate a great potential of soil to store more carbon (Lugato et al., 2014a and 2014b).

Maes et al. (2015b) suggest using net ecosystem productivity (growing biomass, normalised indicator) as an indicator for the flow or use of the service. Based on this indicator, annual carbon sequestration is calculated. Values range from 0-4.3 to 7.4-10.9 ton/ha per year. Between 2000 and 2010, net carbon productivity increased by approximately 10%.

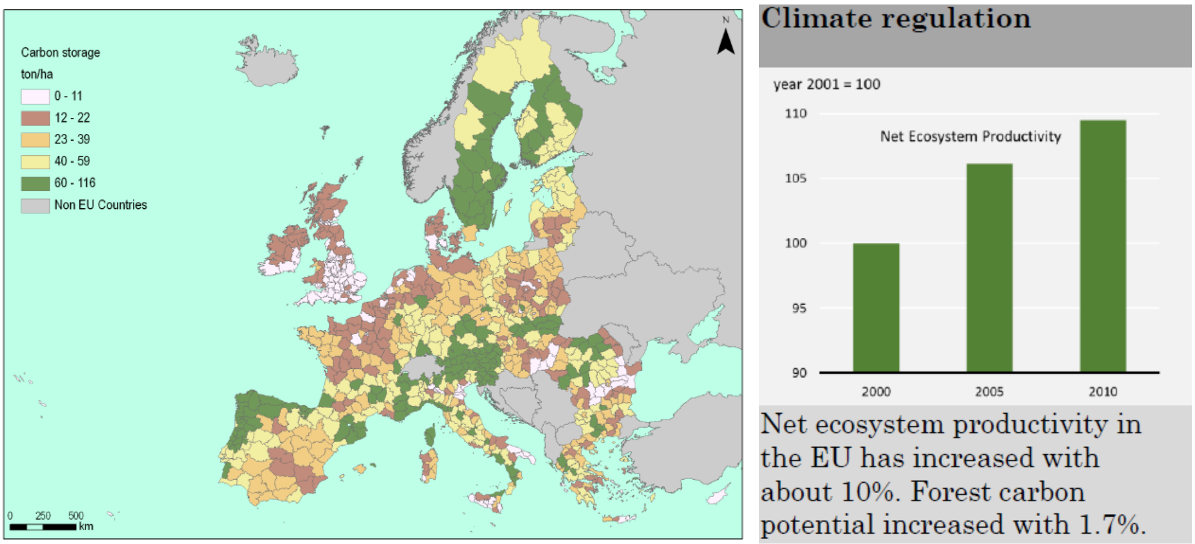


Figure 3.10: Total carbon stock per hectare in the EU in 2000 (MAES et al., 2011) and net ecosystem productivity (MAES et al., 2015b).

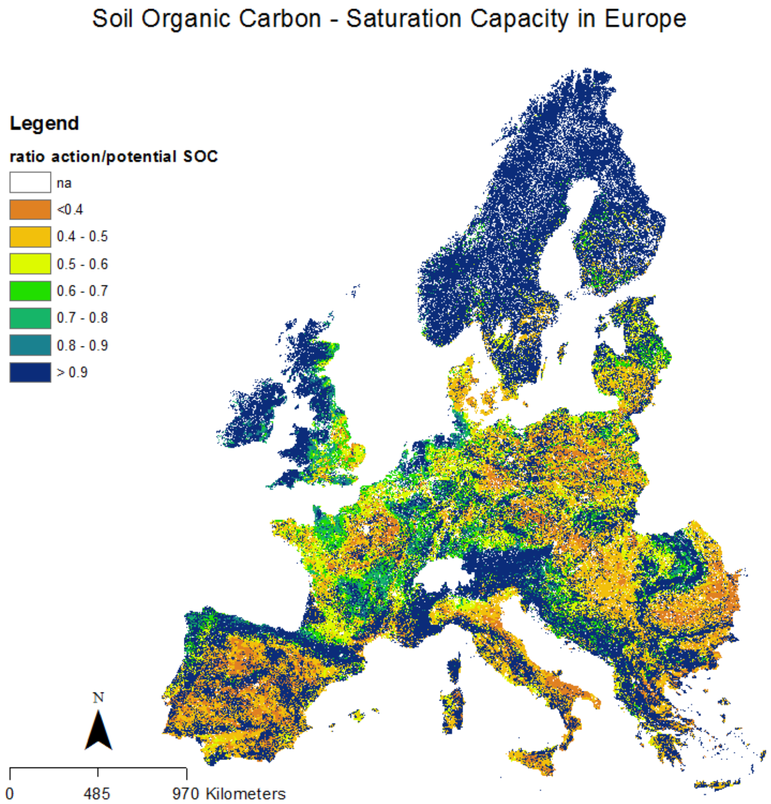


Figure 3.11 Soil Organic Carbon (SOC) saturation capacity. Values close to 0 indicate a great potential of soil to store more carbon (Lugato et al., 2014a and Lugato et al., 2014b)

Regulation of local climate/temperature

The soil influences the potential cooling capacity of green infrastructure. This is especially relevant for urban areas where the urban-heat-island effect occurs. Soil moisture decreases due to evaporation and higher air temperatures. Soil provides the substrate for vegetation, which delivers cooling through shading and through evapotranspiration. Soil moisture is of critical importance. If vegetation suffers from heath or drought stress, leaf stomata will close and transpiration decreases (Pickett et al., 2011). In case of severe drought, vegetation may even lose leaves and as a consequence the shading effect will be impaired. (Van der Meulen et al., 2016).

Geohydrological conditions can be improved by reducing soil sealing and disconnecting roofs from the sewer system to allow more rainwater to infiltrate into the soil. The impact of temperature regulation by the soil-vegetation system on human wellbeing is highly dependent on local spatial links between potential provision and use of this service. Aggregated data at European or national scale cannot be used to conclude e.g. if the potential for this service in urban areas is declining or improving. The water retention index as used by Maes et al. (2015b) may be a suitable indicator if applied at the scale of a city since it integrates direct or indirect indicators for availability of vegetation and soil moisture. Percentage of unsealed soil is also a relevant parameter since open soil is the most favourable habitat for vegetation to provide cooling services. Figure 3.12 shows high differences in the percentage of surface area that is sealed, with highest sealing at the national level in the Netherlands and Belgium (Prokop et al, 2011).The spatial level of information on a European scale gives a useful overview, yet it is not usable for planning purposes or to develop measures on a local scale.

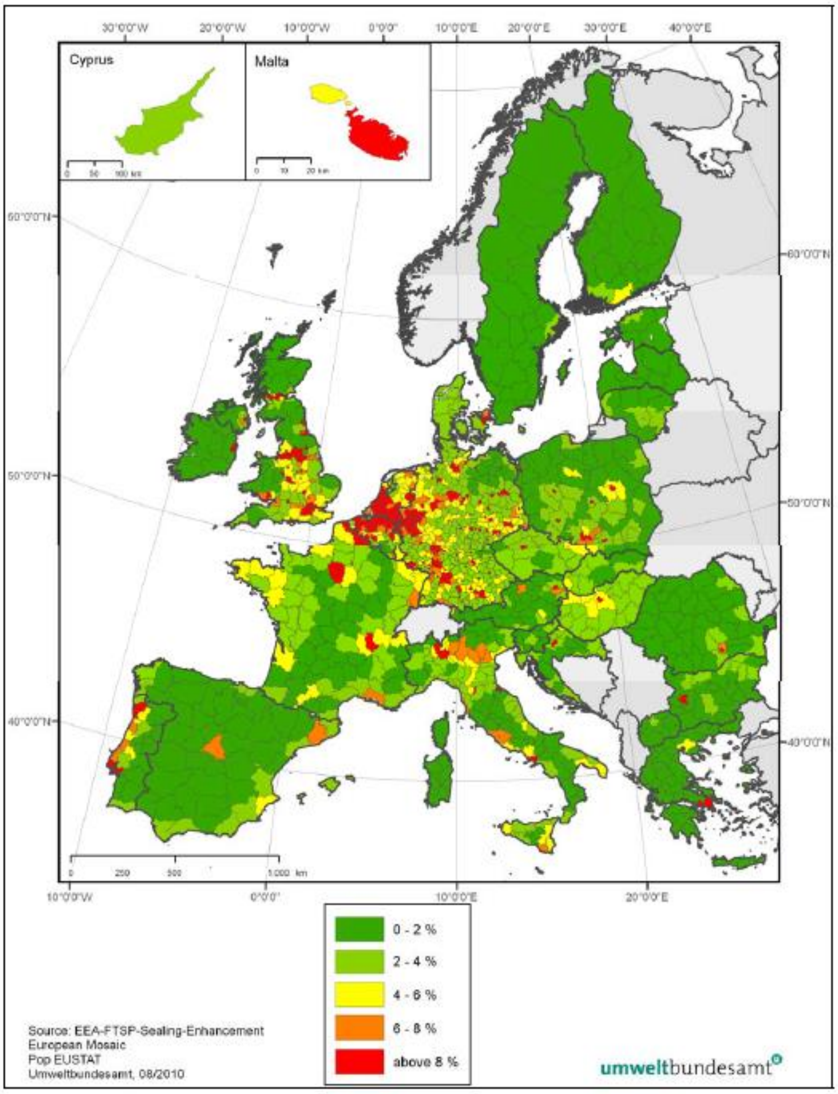


Figure 3.12: Percentage of surface area that is sealed (Prokop et al, 2011).

Noise abatement
The EEA (2014) considers environmental noise pollution as a major environmental health problem in Europe. Noise levels above 55 decibels (dB) affect 125 million people in Europe. This is estimated to cause at least 10,000 cases of premature death in Europe each year. The most dominant source of environmental noise is road traffic. Soil attenuates (traffic) noise, both directly and indirectly by providing substrate for vegetation. Both unsealed soil and vegetation contribute to the attenuation of noise due to adsorption, dispersal and scattering of sound waves. Indirectly, there is also a noise-reducing effect of decreasing wind speeds (Aertsens et al., 2012). Woody vegetation and open, unsealed soil begin absorbing noise frequencies at lower levels than leafy vegetation (see Van Renterghem, 2014, and many references therein). Since noise reduction is provided at a very local level (scale of a street), it is hard to present information in maps at a European level (the required detail will get lost).

Air quality regulation
Unsealed soil can be a sink for air pollutants through deposition processes (Maes et al., 2015b). In contrast, soil may also be a source of pollution in the form of dust as result of wind erosion. Dust may originate from wind erosion and tillage operations in Europe and from sources outside Europe (Sterk and Goossens, 2007). According to Borrelli et al. (2014), soils are most susceptible to wind erosion in the northern European countries, especially sandy soils.

Soils also provide substrate for vegetation which in turn impacts air quality. This impact can be beneficial trough removal of pollutants like particulate matter and nitrogen oxides; on the other hand vegetation can also have adverse effects, for example through negative impact on air circulation. The potential of green infrastructure for air quality improvement is estimated to be less than 1% removal of pollutants (Nowak et al., 2006). Removal of NO_2 by urban green was almost equal between 2000 and 2010 with an increase of 0.8% from 635.5 to 640.3 *1000 ton/year (Figure 3.13; MAES et al., 2015b). Increase in removal may be the result of higher pollutant concentration and/or higher removal potential. In almost all cities that were incorporated in the analysis of 30 cities, NO_2 concentration decreased while green areas expanded. The latter, on average by 1.1%[28], causes the light increase in NO_2 removal, so the potential for the service of air quality regulation increased.

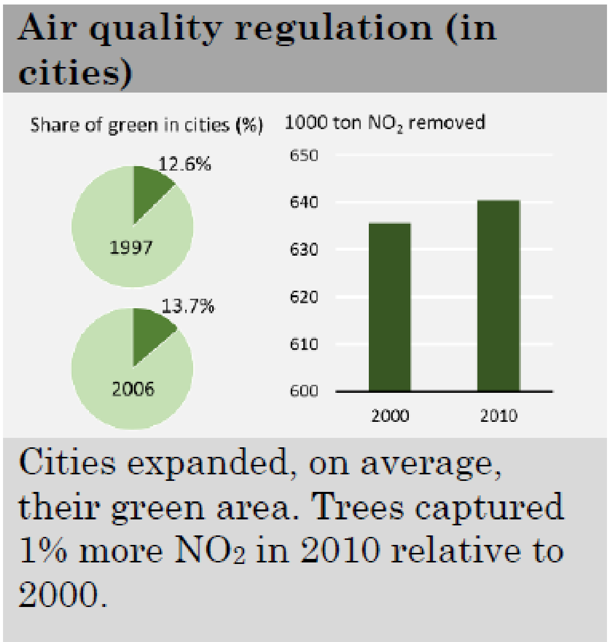


Figure 3.13: Removal of NO_2 (as product of pollutant concentration and removal) and the share of green in cities (Maes et al., 2015b).

3.2.3 Potential and use of cultural services

For cultural ESS only very few assessment studies exist that provide information on the distribution of these services across Europe mainly because of the challenge to generate data. In many cases cultural ESS are only indirectly linked to soil properties (Adhikari and Hartemink, 2016). Available information on this soil ecosystem service is provided below.

Recreation and tourism

Most assessments map cultural ESS by looking at the presence of cultural landscapes (see Figure 3.14 by Tieskens et al. 2017) or they assess aesthetic values at a local or regional scale such as along hiking trails presented by Schirpke et al. (2016) in Figure 3.15. Geomorphological heritage, such as mountain areas, attracts tourists and provides areas for recreational activities.

Figure 3.14, taken from Tieskens et al. (2017), shows that the agricultural as well as forest cultural landscape is unevenly distributed across Europe. Hotspots of agricultural based cultural landscapes are located in many coastal areas of Italy as well as parts of France, whereas in Germany and the

[28] % of urban green areas based on 1997 and 2006.

Western part of Poland so called cold spots exist. Forest landscapes are clearly linked to mountain areas where the cultural landscape index of forests is high compared with lowland regions.

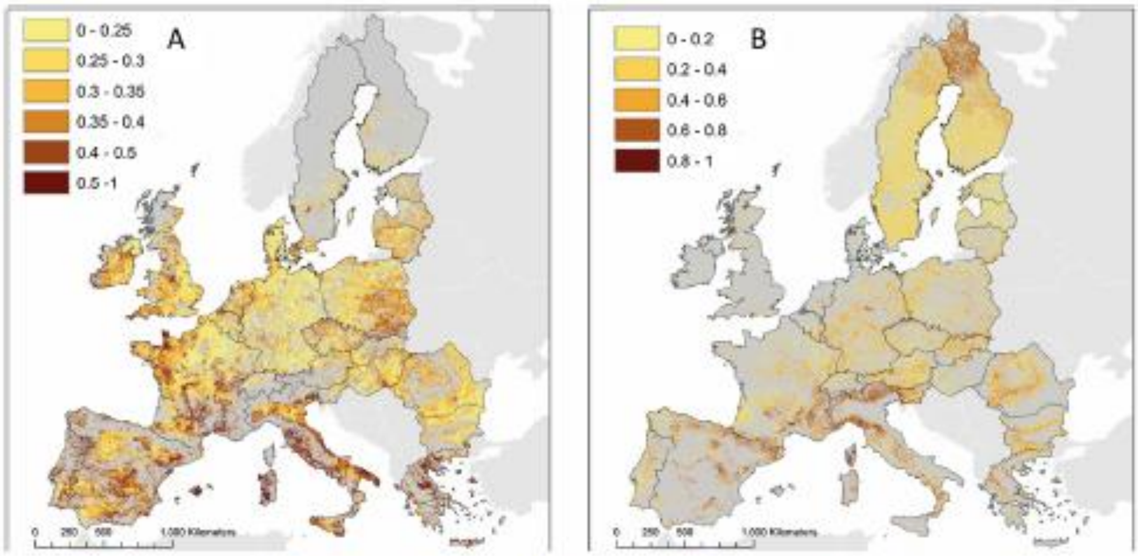


Figure 3.14: Agriculture and forest based cultural landscape index for Europe with relative presence of agricultural land (left hand map) and forest (right hand map) (Tieskens et al., 2017).

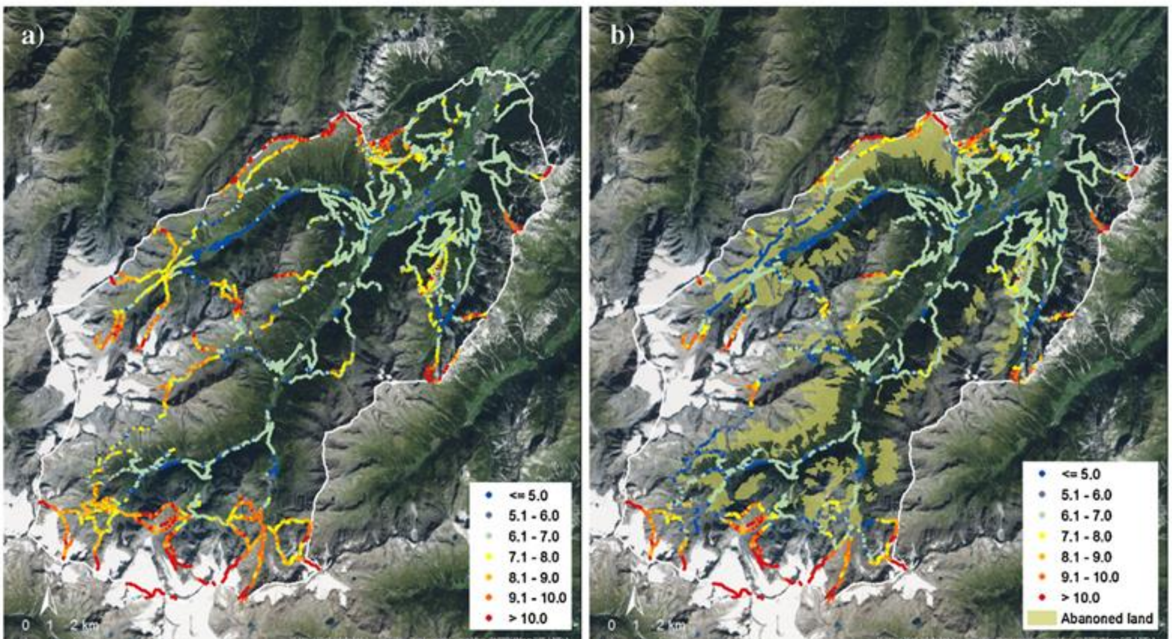


Figure 3.15: Hiking trails that indicate recreation value: for (a) current landscape of Stubai Valley, (b) reforestation scenario of Stubai Valley, Alpine landscape, Austria (Schirpke et al., 2016).

Knowledge/scientific research, cultural and geological heritage, and education
Cultural ESS derived from soil are often linked to "specific locations such as battlefields, ceremonial sites, and cemeteries"(Comerford et al., 2013). The natural characteristics of the soil can enable scientific investigation or education and training in terms that it improves understanding of the Earth's history and of nature. Also soil characteristics can have a certain value for traditional ecological knowledge, cultural or heritage[29]. "Geodiversity" describes the variety in abiotic nature. It refers to the diversity of geological (rocks, minerals, fossils), geomorphological (land form, processes) and soil features. Grey calls specific examples of geodiversity, which have a conservation significance "geoheritage". For example, the World Heritage site of Stonehenge provides several services including intrinsic, economic, aesthetic and spiritual values. In 2004 the Committee of Ministers of the Council of Europe adopted the "Recommendation on conservation of the geological heritage and areas of special geological interest"[30] requesting the recognition of the geological heritage by protecting areas of geological heritage and developing guidelines for their protection.

Kibblewhite et al. (2015) identified the soil properties that affect the preservation of bones, teeth and shells, organic materials, metals, ceramics, glass and stratigraphic evidence. These properties are related to soil types. They found that preservation of gold, lead, ceramics, glass and phytoliths[31] is good in most soils but that degradation rates of other materials are strongly influenced by soil type. Soil types with a high preservation potential for materials are dry soil types such as Calcisols, Gypsisols and some drier Leptosols, that are mostly limited to small areas in Spain and Greece. Another good preservation environment is provided by soils that are permanently waterlogged and strongly anaerobic and where groundwater is alkaline. This is typical for Eutric Histosols in some lowland peatlands in Northern and Western Europe. Fluvisols are important for the preservation of stratigraphic evidence of the cultural and environmental context of materials. Maps are available, based on soil type, showing the relative preservation capacity of soils for different materials. Figure 3.16 shows the example of preservation capacity for organic materials. Soil erosion, or drainage in peat soils, can damage cultural heritage archives or environmental and cultural information (EEA 2016a).

[29] CICES https://cices.eu/ V5.1
[30] https://wcd.coe.int/ViewDoc.jsp?p=&Ref=Rec(2004)3&Language=lanEnglish&Ver=original&Site=CM&BackColorInternet=C3C3C3&BackColorIntranet=EDB021&BackColorLogged=F5D383&direct=true
[31] Phytoliths are siliceous plant remains that tell something about the environment of the past and land management

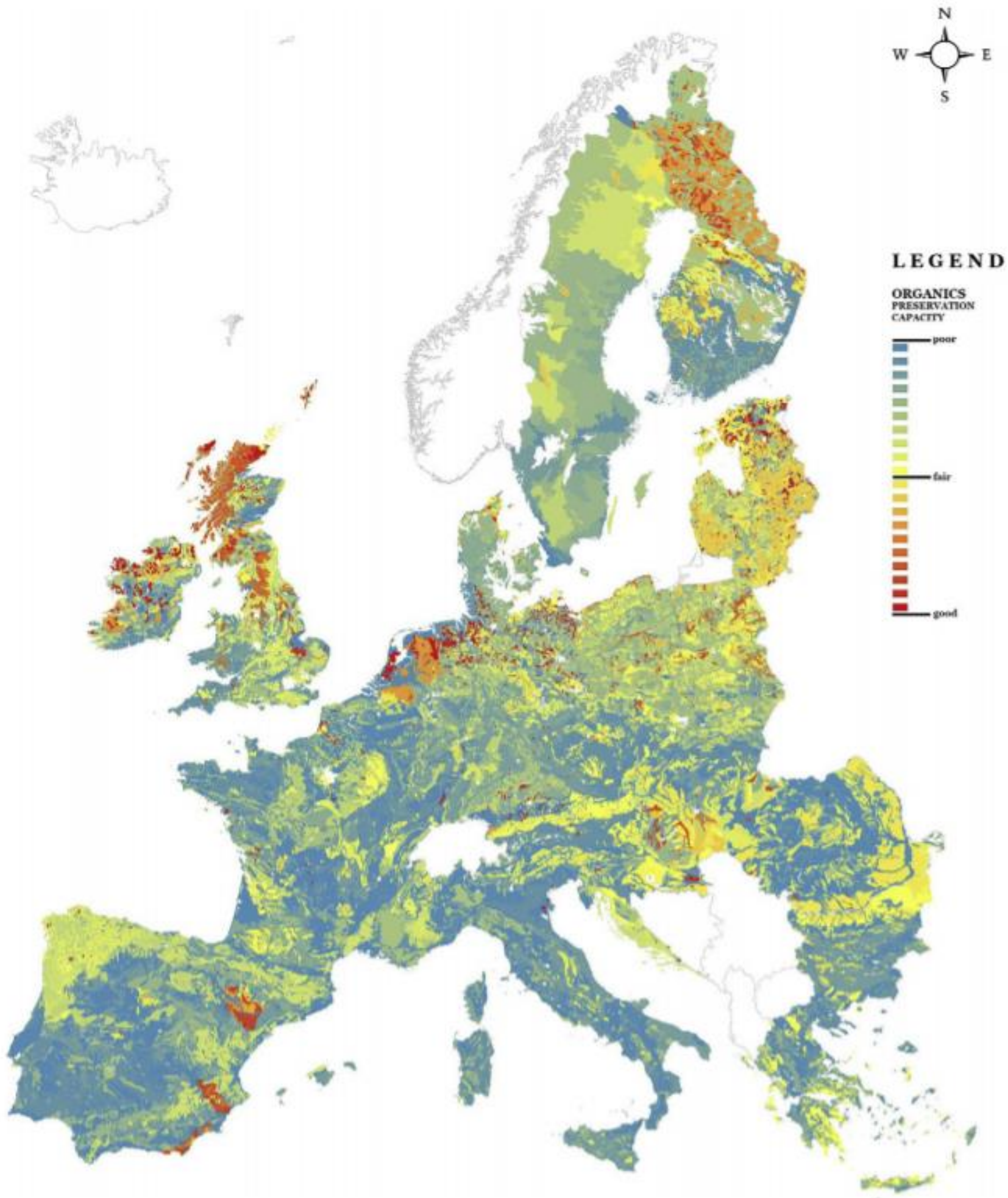


Figure 3.16: Relative soil-based preservation capacity for organic materials buried in soil including plant material (e.g., wood, fibres, fruits, seeds, and pollen), fungal spores, insects and their larvae, parasite eggs and the remains of animals and humans (e.g., skin, soft tissues)." (from Kibblewhite et al., 2015).

Figure 3.17 shows a map of the European Geoparks network. Geoparks are defined as territories that 'include a particular geological heritage and a sustainable territorial development strategy supported by a European program to promote development. It must have clearly defined boundaries and sufficient surface area for true territorial economic development.'

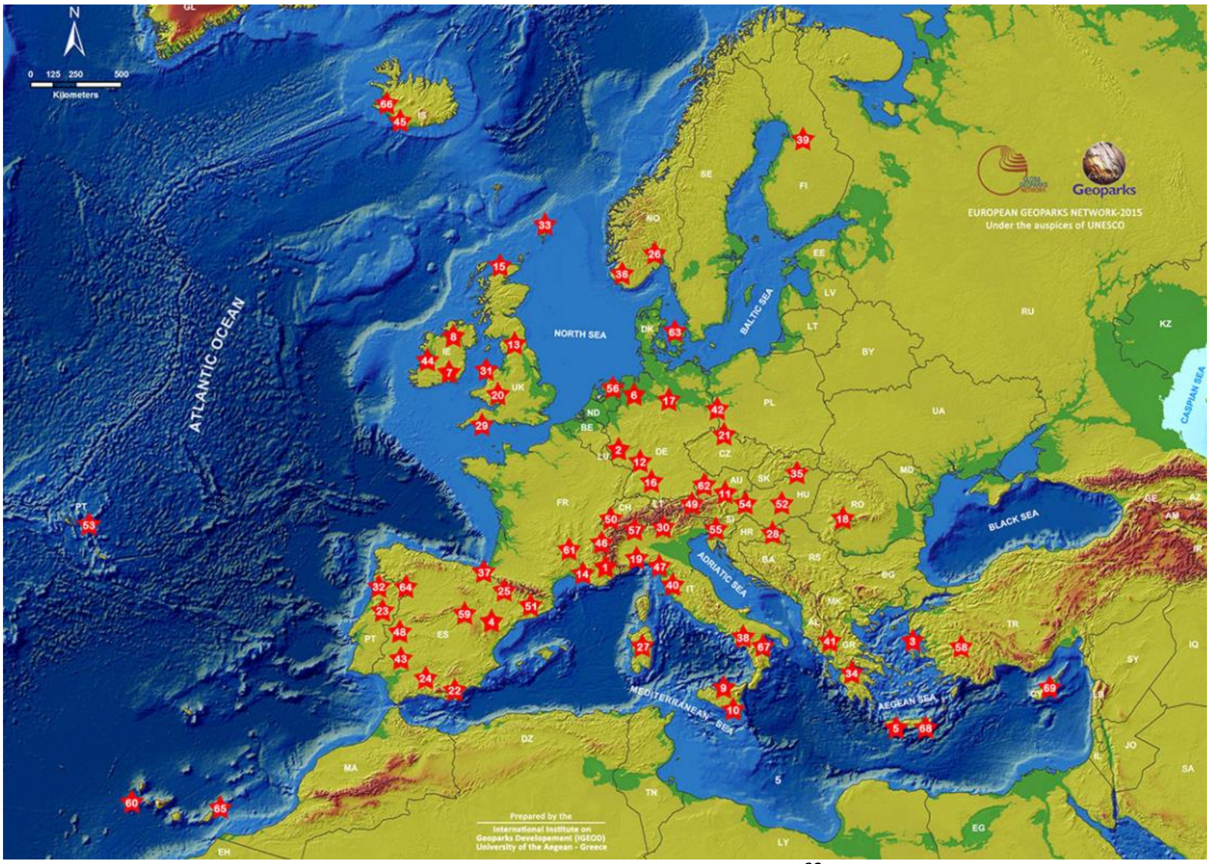


Figure 3.17: Geoparks as part of the network of Geoparks in Europe[32]

Spiritual and symbolic experience

Green spaces or natural landscapes are prominent examples of cultural ESS, and so are traditional knowledge and management systems about sustainable management practices (Tengberg et al., 2012). It is difficult to find information on cultural services in studies of soil ecosystem services. Dominati (2010) names this as a curious omission. “Soils, as part of landscapes that support vegetation, have across many cultures been a source of aesthetic experiences, spiritual enrichment, and recreation. Many deities and religious beliefs refer specifically to the earth and its sacredness and soils also have various cultural uses across the globe from being a place to bury the dead, a material to build houses or a place to store and cook food” (Dominati et al., 2010). We found no European data on the potential and flow of spiritual services.

3.3 Availability of information on ESS status in Europe

The contribution of soil to many ESS is poorly understood or described. The JRC report on trends in ESS in the EU between 2000 and 2010 by Maes et al. (2015b) highlights how finding data to map and assess ESS is a challenge, especially for regulating services. Most information included in the trend analysis only considers the supply side. We confirm this observation. Moreover, we also see that most information on provisioning services focuses on the use or flow of services. Only for a limited set of soil ESS are data on the potential of ecosystems to deliver these services available. Table 3.2 a-c provides an overview of indicators that have been suggested in literature, as well as an estimation of the availability and scale of data.

Table 3.2a-c uses the CICES **Sections** (provisioning services, regulating services and cultural services).

[32] Map from www.europeangeoparks.org

- In the first column the **soil ecosystem service** is described. The 1 or 2 behind the ecosystem service indicates respectively whether it is a primary (direct) or secondary (indirect) soil ecosystem service.
- In the second column the CICES **Class**[33] is mentioned.
- The third column gives the CICES **Class type**[34].
- The fourth column shows the available **indicator** to measure the ecosystem condition or the quantity of an ecosystem service [and their **unit** between brackets].
- The fifth column specifies if the indicator is aiming to show the ESS **supply** or **use**.
- Then the relevant spatial extent for the indicator is given (regional, local).
- The **availability of data** can be found in the seventh column.
- The last column, gives the indication of the **strength of the indicator**. This strength can be determined by i) data availability and ii) ability to convey information to the policy making and implementation processes (see figure 3.18).

The table remains incomplete and should be further refined. Inputs were partly based on the second MAES working paper (MAES, 2014) and the MAES urban pilot (Maes, 2016).

The indicators that are suggested here were each evaluated according to 2 criteria: i) data availability and ii) ability to convey information to the policy making and implementation processes (4).

● available indicator to measure the condition of an ecosystem, or the quantity of an ecosystem service at a given CICES level for which harmonised, spatially-explicit data at European scale is available and which is easily understood by policy makers or non-technical audiences. Spatially-explicit data in this context refer to data that are at least available at the regional NUTS2 level or at a finer spatial resolution. CICES classifies ecosystem services at 4 hierarchical levels. Sometimes, it is more cost-effective to consider an assessment of ecosystem services at a higher CICES level than at class level, especially if aggregated indicators are available. Indicators that aggregate information at higher hierarchical CICES level can therefore also have a green label.

● available indicator to measure the condition of an ecosystem, or the quantity of an ecosystem service at a given CICES level but for which either harmonised, spatially-explicit data at European scale is unavailable or which is used more than once in an ecosystem assessment, which possibly results in different interpretations by the user. This is typically the case for indicators that are used to measure ecosystem condition, which are reused to assess particular ecosystem services. This colour also includes indicators that capture partially the ecosystem service assessed.

● available indicator to measure the condition of an ecosystem, or the quantity of an ecosystem service at a given CICES level but for which no harmonised, spatially-explicit data at European scale is available and which only provides information at aggregated level and requires additional clarification to non-technical audiences. This category includes indicators with limited usability for an ecosystem assessment due to either high data uncertainty or a limited conceptual understanding of how ecosystems deliver certain services or how ecosystem condition can be measured. The ability to convey information to end-users is limited and further refined and/or local level assessments should be used for verifying the information provided by this type of indicators.

● unknown availability of reliable data and/or unknown ability to convey information to the policy making and implementation processes.

Figure 3.18: scale for indicator strength (MEAS, 2014).

For provisioning services (Table 3.2a), most information is available for agricultural and forestry production, so the actual use or flow. To gain more insight in the sustainability of the use, production should be linked to soil and groundwater quality and impact on other ESS, like it was

[33] The CICES class level provides a further sub-division of group categories into biological or material outputs and bio-physical and cultural processes that can be linked back to concrete identifiable service sources.

[34] The CICES class types break the class categories into further individual entities and suggest ways of measuring the associated ecosystem service output. (such as Crops by amount, type)

done for Flanders (Stevens et al., 2014) in Table 3.3. For fresh water provision, most European studies report total water availability, use and retention without specifying results for groundwater. For a better insight in the capacity of soils to provide fresh water, it is advisable to study aspects as water regulation and purification in the soil in more detail. For thermal energy both relative potential and demand are known for Europe. A useful source of information on demand for heat is the 4th Pan-European Thermal Atlas[35] which covers the 14 EU member states together comprising about 90% of the total heat market of the European Union.

For regulating services (Table 3.2b) no European maps are easily available, so only indirect indicators could give an idea of the status of the potential to deliver these services. Examples are soil pressures to soil biodiversity and soil sealing as threat to air quality regulation, local climate regulation and noise abatement. In the future, data could be extracted from both local and regional sources to construct European information. Most studies use carbon sequestration or carbon stock as an indicator for climate change mitigation. However, in this way important greenhouse gasses regulated by soil processes are neglected. For example, another major greenhouse gas is nitrous oxide. Lugato et al., recently (2017) published data on emissions from agricultural soils.

Cultural ESS (Table 3.2c) are not as tangible as other services and only few studies focus on these. They are often non-material and therefore rarely quantified (Tengberg et al., 2012), one reason why they are still marginalized in decision making (MA, 2005). As a result, little information can be provided about the capacity of soils to provide these services. In general, at least soil fertility and water regulation are important aspects for provision of recreation areas. This role of soil in enabling cultural services to be provided could be elaborated further.

Several projects will provide more relevant data in the near future. Chapter 8 provides an overview of some relevant projects and describe what they will deliver.

[35] PETA4 http://www.heatroadmap.eu/Peta4.php

Table 3.2a: Indicator frame for provisioning soil ecosystem services

Ecosystem service			Indicator frame			
Ecosystem Service	**CICES class**	**CICES class type**	**Indicator [unit] & Strength of indicator**	**Supply or Use**	**Relevant spatial extent**	**Availability of data**
Biochemical and pharmaceuticals (1)	*No class provided in CICES (CICES Division= Materials)*	*No class type provided in CICES*	Raw materials for medicines [...]	S	Regional	European data for potential and use, as well as the role of soil are not found
Food, wood and fibre (1)	Cultivated terrestrial plants (incl. fungi, algae) grown for nutritional purposes or as a source of energy; Fibres and other materials from cultivated pants fungi, algae and bacteria for direct use or processing.	Crops by amount, type	Surface area of organic crops [ha] Yields (ton/ha) Forest biomass stock (tons)	S	Regional	Data on production are available on European scale
Fresh water(1)	Ground (and subsurface) water for drinking or non-drinking purposes	By amount, type, source	Water retention index [dimensionless, between 0-10] Water abstraction (m^3 /yr)	S U	Regional Regional	There are data on water retention and water abstraction available on European scale
Carrying capacity for infrastructure, buildings and animals [support of animals and infrastructure][carrier function] (1)	*No class provided in CICES*	*No class type provided in CICES*	Suitability classes for building [-]	S	Local	There are no European data found but regional or national data may be used at the local level
Raw materials (1)	Mineral substances used for nutritional or material purposes or as energy source	Amount by type	Raw material extraction (tons/yr)	S	Regional	Current EU-covering projects did not yet deliver data on potential delivery or actual flow.
Thermal energy (1)	Ground water (and subsurface) used as an energy source; Geothermal	By amount & source, amount by type	Suitability classes for ATES [-] Demand based on above ground land use [PJ]	S U	Local Local	There are indicative data on suitability and demand on European scale

Table 3.2b: Indicator frame for Regulation and maintenance soil ecosystem services

Ecosystem service			Indicator frame			
Ecosystem Service	**CICES class**	**CICES class type**	**Indicator [unit] & Strength of indicator** ●●●●	**Supply or Use**	**Relevant spatial extent**	**Availability of data**
Water purification and soil contamination reduction (1)	Bio-remediation by micro-organisms, algae, plants, and animals; Filtration /sequestration /storage/accumulation by micro-organisms, algae, plants, and animals; Mediation of waste toxics and other nuisances by non-living processes	By type of living system or by waste or substance type; amount by type	● Nitrogen removal [dimensionless scale of 1-5] ● Concentration of pollutants in soil (mg/kg)	S U	Regional Local	No EU-wide data found
Water regulation (1)	Hydrological cycle and water flow regulation (including flood control and coastal protection);	By depth/volumes	● Retention capacity of water in soils [dimensionless, between 0-10]	S	Regional	No EU-wide data found
Pest and disease control (2)	Pest control (including invasive species); Disease control	By reduction in incidence, risk, area protected	● For agricultural land: density of hedgerows (m / ha)	S	Regional	No European maps on biological control of pests and diseases. European map of threats to soil biodiversity may be relevant for future changes in soil biodiversity as indictor for pest and disease control
Carbon Sequestration (1)	Weathering processes and Decomposition and fixing processes and their effect on soil quality	By amount/concentration and source	● Carbon Sequestration [ton/ha/yr] ● Net ecosystem productivity	S S	Regional Regional	insufficient EU-wide data found. C storage in forests are available, but not for other land uses (storage per unit of area)
Regulation of greenhouse gasses (2)	Regulation of chemical composition of atmosphere and oceans	By contribution of type of living system to amount, concentration and climatic parameter				
Regulation of local climate/temperature (2)	Regulation of temperature and humidity, including ventilation and transpiration	By contribution of type of living system to amount, concentration and climatic parameter	● Water retention index if applied at the scale of e.g. a city ● Uncovered soil	U U	Local Local	Data on a local scale might be available
Noise abatement (2)	Noise attenuation	By type of living system	● Leaf Area Index + distance to roads (m)	S	Local	data provision on local level

Air quality regulation (2)	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals; Mediation of waste toxics and other nuisances by non-living processes	By type of living system or by water or substance type; amount by type	● Pollutants removed by vegetation (in leaves, stems	S	Local	data provision on local level

Table 3.2c: Indicator frame for cultural soil ecosystem services

Ecosystem service			Indicator frame			
Ecosystem Service	**CICES class**	**CICES class type**	**Indicator [unit] & Strength of indicator** ●●●●	**Capacity or Demand**	**Relevant spatial extent**	**Availability of data**
Recreation and tourism (2)	Characteristics of living systems that enable activities promoting health recuperation or enjoyment through active or immersive interactions; or through passive or observational interactions; natural abiotic characteristics of nature that enable active or passive and experiential interactions	By type of living system or environmental setting; amount by type	● Number of visitors ● Distribution of sites	U S	Local Regional	No data on European scale
Knowledge/scientific research, Cultural heritage and education (1)	Characteristics of living systems that: enable scientific investigation or the creation of traditional ecological knowledge; enable education and training; are resonant in terms of culture or heritage; enable aesthetic experiences; natural abiotic characteristics of nature that enable intellectual interactions.	By type of living system or environmental setting; amount by type				
Spiritual and symbolic experience (2)	Elements of living systems: that have symbolic, sacred or religious meaning; used for entertainment or representation; natural abiotic characteristics or features of nature that enable spiritual, symbolic and other interactions.	By type of living system or environmental setting; amount by type				

3.4 The relevance of quantifying the provision of ESS for land management

Information on the potential of soil to provide specific ESS may support land managers, policy makers and urban planners in well-informed planning and decision making. Knowing the current status and future trends enables prioritization of actions to tackle soil pressures and supports the development of soil management strategies to optimize the provision of combinations of ESS that are most important to human wellbeing. In order to assess whether the use of specific services is sustainable, it is important to also consider the trade-offs between the potential supply, actual use and future demand of multiple soil ecosystem services. The use of one service may result in reduced capacity of the soil to provide other services or in competition between different users. For example, fresh groundwater abstraction by one user may limit the availability to others. This is why ecosystem assessments should consider multiple spatial and temporal scales.

Table 3.3 shows an example from the Netherlands (Dirkx, 2014) and Belgium (Flanders) (*Stevens et al., 2014)* where trends in demand and supply of soil ecosystem services are described. Because the studies differ in set up, different types of information and signs are combined in the table. The analysis of potential supply and use gives an indication of the sustainability of the use of ecosystem services.

Table 3.3: Use and supply of ecosystem services in Flanders (based on Stevens et al., 2014) and the Netherlands (based on Dirkx, 2014). ↑/↗: increase/minor increase; ↘: minor decrease; >/>>: demand higher/much higher than supply →/←/=: increase/decrease/stable

Ecosystem service	**Flanders, trends in the last decades (Stevens et al., 2014)**				**The Netherlands, changes in national demand and supply (national + international) between 1990 and 2013 (Dirkx, 2014)**		
	Demand		**Supply**	**Use**	**Demand**	**Supply**	**More than 50% of use supplied by:**
Biochemical and pharmaceuticals	Not included in analysis				Not included in analysis		
Raw materials	Not included in analysis				Not included in analysis		
Thermal energy	Not included in analysis				Not included in analysis		
Food production	↑	>	↑	Unbalance between supply and demand and/or strong negative impact on other ESS	→	→	Dutch ecosystems
Timber production	↗	>>	↗	Unbalance between supply and demand and/or strong negative impact on other ESS	←	=	Import/technical alternative/demand not fulfilled
Energy crops production	↑	>>	↑	Unbalance between supply and demand and/or strong negative impact on other ESS	→	→	Import/technical alternative/demand not fulfilled
Fresh water [Water production, FL] [Drinking water and non-drinking water, NL	↘	>	↘*	Vulnerable balance between supply and demand and/or negative impact on other ESS	= (non drinking) → (drinking)	←	Dutch ecosystems
Water purification and soil contaminant reduction [Water quality regulation]	↗*	>>	↑	Unbalance between supply and demand and/or strong negative impact on other ESS	←	=	Import/technical alternative/demand not fulfilled

Ecosystem service	**Flanders, trends in the last decades (Stevens et al., 2014)**				**The Netherlands, changes in national demand and supply (national + international) between 1990 and 2013 (Dirkx, 2014)**		
	Demand		**Supply**	**Use**	**Demand**	**Supply**	**More than 50% of demand supplied by:**
Water regulation [water storage, NL]	Not included in analysis				→	→	Import/technical alternative/demand not fulfilled
Pest and disease control [pest regulation]	↗*	>>*	↘*	Unbalance between supply and demand and/or strong negative impact on other ESS	→	←	Import/technical alternative/demand not fulfilled
Carbon Sequestration	Not included in analysis				→	←	Import/technical alternative/demand not fulfilled
Regulation of greenhouse gasses	Not included in analysis						Import/technical alternative/demand not fulfilled
Regulation of local climate/temperature [cooling in cities, NL]	Not included in analysis				→	=	Import/technical alternative/demand not fulfilled
Air quality regulation	↓	>>	↑	Unbalance between supply and demand and/or strong negative impact on other ESS	Not included in analysis		
Noise abatement [noise regulation]	↗*	>	→	Vulnerable balance between supply and demand and/or negative impact on other ESS	Not included in analysis		
Flood protection	↑	>>	↑	Unbalance between supply and demand and/or strong negative impact on other ESS	Not included in analysis		
Coastal protection	↑	>	↘	Unbalance between supply and demand and/or strong negative impact on other ESS	→	=	Import/technical alternative/demand not fulfilled
[Green space for outdoor activities, FL] [Green recreation, NL]	↑*	>	↘*	Unbalance between supply and demand and/or strong negative impact on other ESS	→	=	Dutch ecosystems
Cultural heritage	Not included in analysis				=	=	Dutch ecosystems
Symbolic value nature	Not included in analysis				=	=	Import/technical alternative/demand not fulfilled

*reliability of data low or unknown

4 Indicators for soil (ecosystem) condition

4.1 Soil condition in the context of MAES

Soil in the context of MAES has been considered as an ecosystem. Nevertheless, because soil is a cross-cutting component that supports all other MAES terrestrial ecosystem types, the approach to incorporate soil information, such as data and indicators, in the MAES framework is twofold. First, a soil component has to be taken into account in all MAES ecosystem types (i.e. dedicated part of all other MAES pilots) in order to have a more comprehensive overview of ecosystem condition. Second, chapter 3 started to provide an overview of the ecosystem services delivered by soil overall, independently from the MAES ecosystem type. A first attempt was made to develop an indicator framework for the assessment of soil ecosystem services.

An ad-hoc EU expert meeting on 15 May 2017 resulted in a proposal for soil indicators to be included in the MAES indicator framework for ecosystem condition. Such proposal follows the steps recommended by the common analytical framework paper for mapping and assessment of ecosystem condition.

Soil is in good condition when it has low pressures on it. Soil condition can be measured in a functional and structural way. A functional approach for the assessment of soil condition is based on indicators which measure the performance of soil functions. This answers the following question: what is the condition needed to deliver a given function? Examples are water holding capacity or soil carbon content. These indicators can be coupled to specific soil functions, hence to ecosystem services (e.g. fresh water supply and regulation of local climate / temperature).

A structural approach to soil condition is based on indicators that measure the condition of soils, assuming that physicochemical and biological soil properties contribute to the provision of ecosystem services. An example is microbial diversity.

Table 4.1 proposes soil indicators to be included in assessments of ecosystem condition. The table contains indicators for each of the seven terrestrial MAES ecosystem types. Each indicator is assigned to pressure or condition. Some indicators are ecosystem-type specific whereas most indicators are shared by different ecosystem types. The design of the table attempts to make this clear. For instance, the indicator “bulk density” is relevant to urban, cropland and grassland, forest and wetlands.

The following indicators cover most MAES ecosystem types and could represent an essential set to include in MAES ecosystem condition assessments:

- Soil erodibility (K-factor (tonne ha h/MJ mm))
- Soil sealing (ha/year) (+ Land take (% year)
- Soil contamination (sites, from point or diffuse sources, nutrient deposition)
- Available water capacity (mm/year)
- Soil nutrient availability (nitrogen & phosphorus) (mg/kg)
- Soil organic carbon (SOC) (g/kg)
- Soil biodiversity (DNA-based richness and abundance)

The indicators of Table 4.1 are commented in Table 4.2 and coupled to possible data sources for their quantification. Currently, the main gaps are on biological soil properties (i.e. soil biodiversity distribution). Nevertheless, the next LUCAS Soil survey, scheduled for 2018, will produce the first large-scale dataset for soil biodiversity in the EU (expected release in 2019 or early 2020).

Clearly, several indicators will prove to be correlated to each other: soil carbon content is a function of land management practices while it may be related to soil biodiversity. Therefore, a further distinction could be made between indicators that measure the intrinsic condition of soils and indicators that measure pressures. For instance, Natura 2000 sites have, on average, 10% more carbon in their topsoil than non-protected areas. Therefore, carbon content can be considered as an essential indicator which suitably captures the condition of soils. However, the inclusion of additional indicators which quantify pressures may be interesting to understand spatial and temporal patterns in soil carbon.

Most of the indicators of Table 4.1 have a dependency on soil type. This means that the interpretation of the indicator (the value at a specific moment, the change over time, and threshold values between which soils are considered in good condition) varies as a function of soil type. Such information is important to understand the links among soil pressures, soil condition and soil biodiversity.

Table 4.1: A proposal for soil indicators to map and assess ecosystem condition (based on Maes et al., 2018)

	ECOSYSTEM						
	Urban	Cropland	Grassland	Forest & woodland	Heathland & shrub	Sparse vegetation	Wetland
	Soil pressures*						
Habitat conversion and degradation (land conversion)	Soil sealing (ha/yr)	Land take (%/yr)		Soil sealing (ha/yr)			
		Intensification / extensification		Landslides (number/yr, area/yr)	Change of area due to conversion (%/yr)		
Climate change		Past trend in soil moisture content ($l/m^3/10$ yr)		Change in soil moisture (water stress) (index)			
Pollution and nutrient enrichment		Gross nutrient balance (P, N) (kg/ha/yr)		Excessive nutrient loading: Nitrogen in soil (kg/ha/yr) C/N ration in soil (ratio)	Critical load exceedance for nitrogen (eq/ha/yr)		Exposure to eutrophication (mol nitrogen eq/ha/yr)*
				Industrial (point) and diffuse soil pollution (heavy metals concentration) (mg/kg/yr)			
Over-exploitation		Water abstraction (million m^3/yr)					
Others		Soil erosion (tonne/ha/yr)					
		Loss of organic matter (% SOC/yr)					Loss of organic matter (%SOC/yr)

<table>
<tr><th></th><th>Urban</th><th>Cropland</th><th>Grassland</th><th>Woodland and forest</th><th>Heathland and shrub</th><th>Sparse vegetation</th><th>Wetland</th></tr>
<tr><td></td><td colspan="7">Soil condition</td></tr>
<tr><td rowspan="3">Environmental quality</td><td>Imperviousness (%)</td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">Sites with contaminated soil (number)</td><td colspan="2">Nitrogen in groundwater in nitrogen vulnerable zones (mg/l)</td><td rowspan="2">Concentration of nitrogen, sulphate, sulphur, calcium and magnesium (kg/ha)</td><td colspan="2" rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">Heavy metal concentration in soil (mg/kg)</td></tr>
<tr><td rowspan="6">Structural soil attributes</td><td colspan="4">Bulk density (kg/m^3)</td><td colspan="2"></td><td>Bulk density (kg/m^3)</td></tr>
<tr><td colspan="7">Soil organic carbon (SOC) (g/kg)</td></tr>
<tr><td colspan="7">Soil biodiversity (DNA-based richness and abundance)</td></tr>
<tr><td>Earthworms (number, number/ha)</td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td></td><td colspan="3">Soil pH (pH)</td><td colspan="2"></td><td></td></tr>
<tr><td></td><td colspan="5">Soil erodibility (K-factor (tonne ha h/MJ mm))</td><td></td></tr>
<tr><td></td><td></td><td colspan="2"></td><td>soil moisture (water stress) (index)</td><td colspan="2"></td><td>soil moisture (%)</td></tr>
<tr><td rowspan="2">Functional soil attributes</td><td colspan="3">Available water capacity (mm/yr)</td><td colspan="4">Available water capacity (index)</td></tr>
<tr><td></td><td colspan="5">Soil nutrients availability (nitrogen & phosphorus) (mg/kg)</td><td></td></tr>
</table>

**The Soil Pressures have some overlap with the Soil Threats in the Soil Thematic Strategy (Erosion, Decline in organic matter, Local and diffuse contamination, Sealing, Compaction, Decline in biodiversity, Salinisation, (Floods and) landslides, Desertification. See also figure 2.3 and table 5.1, but do not overlap completely: Compaction is “hidden” in Soil Condition – bulk density, (Loss of) soil biodiversity is an indicator for ecosystem condition, salinization is ”hidden” in Pressures - Pollution and nutrient enrichment and in Soil Condition – Environmental quality. Desertification is not in this table at all but its impacts could be measured with indicators such as Loss of organic matter and indicators under Habitat conversion and degradation.*

Table 4.2: Comments on the indicators and link to the data sources

Group	Pressures	Indicator	Data or data availability
Soil pressures	Habitat conversion and degradation (land conversion)	Agricultural land management intensity	FSS (ESTAT) Agri-environmental indicator[36] – tillage practices (EUROSTAT)
		Forest management intensity	EUROSTAT data Forest management indicator (EEA/ETC-ULS) Dominant forest management approach in Europe (FMA) (Alterra)
		Soil sealing	Copernicus / CORINE Land Cover Degree of soil sealing (%) (Human Settlement Layer – JRC)
		Landslides	Landslides Database Landslide Susceptibility (ELSUS)
		Land use change	CORINE Land Cover / Copernicus
	Climate change	Soil Moisture	EO data (Climate variables) Soil moisture active passive (SMAP) data (NASA)
	Pollution and nutrient enrichment	Sites with contaminated soil, from point or diffuse sources	LUCAS data (heavy metals + pesticides in 2018) JRC Climate Unit might have something on nutrient deposition
		Gross nutrient balance	EUROSTAT data
	Over-exploitation	Water abstraction	Aquastat FAO
	Other	Loss of organic matter	LUCAS data Average eroded SOC in agricultural soils (JRC-2013) Global Soil Organic Carbon Map (GSOCmap) FAO
		Soil erosion	JRC-ESDAC data

[36] This was a single survey. It would be useful if repeated at regular intervals.

Group	Pressures	Indicator	Data or data availability
Soil Condition	Environmental quality	Imperviousness	Copernicus Imperviousness and imperviousness changes (Copernicus/EEA)
		Sites with contaminated soil /heavy metals in soil	Indicator on soil contamination management (EEA/EIOnet) LUCAS data (heavy metals + pesticides in 2018)
		Nutrient concentrations	EUROSTAT data JRC Climate Unit might have something on nutrient deposition
	Structural soil attributes	Soil organic carbon	LUCAS data Global Soil Organic Carbon Map (GSOCmap) FAO
		Bulk density	LUCAS data
		Soil biodiversity	ETC/ULS and EEA
		Earthworms	Map of earthworm at EU level and national data (Programme Earthworm watch UK, Bio-indicator programme FR, Germany, others?
		Soil pH	LUCAS data
		Soil erodibility	JRC-ESDAC data
		Soil moisture	EO data (Climate variables) Soil moisture active passive (SMAP) data (NASA)
		Available water capacity	Topsoil physical properties (LUCAS data)
		Soil nutrients availability	LUCAS data

4.2 A reference for ecosystem condition based on soil condition

Table 4.1 makes a proposal for an indicator set to map and assess soil condition but it does not include threshold or target ranges that qualify soil as being in good condition. This raises the question of a reference condition against which to evaluate present condition of ecosystems. The interpretation of most indicators is dependent on the soil type. This information is not yet included in the table but soil type will be an important determinant for setting a reference.

The MAES urban pilot (MAES, 2016) listed several approaches to set a reference condition. They are based on policy targets (present or new targets), precautionary threshold values, a reference condition (e.g. pristine soils) or an analysis of the range of indicator values with a reference set using quantiles.

In absence of EU soil legislation, there are no mandatory or very precise / quantitative policy targets, and neither reference, nor threshold values established at EU level. This is part of soil policy development to be undertaken by the Commission with the support of the EU expert group on soil protection. The ENVASSO[37] project has delivered information particularly useful to help define a reference for ecosystem condition based on soil pressure indicators. A special report (Huber et al., 2008) identifies 290 potential indicators relating to 188 key issues for nine threats to soil identified in the Commission's Thematic Strategy for Soil Protection[38] (see table 5.1). Sixty indicators that address 27 key issues, covering all these threats, were selected on the basis of their thematic relevance, policy relevance and data availability. Baseline and threshold values are presented and three priority indicators for each threat are identified. Factsheets describe the priority indicators in more detail.

[37] ENVironmental ASsessment of Soil for mOnitoring The ENVironmental ASsessment of Soil for mOnitoring funded under the 6th Framework Programme, for a description see chapter 8 and Annex III.

[38] COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection

5 Soil pressures at EU level

Soil is increasingly degrading, both in the EU and at global level (EEA, 2015b). The "Thematic Strategy for Soil Protection" (STS)[39] acknowledged already in 2006 that soil degradation is a serious problem. Different forms of soil degradation can eventually reduce the capacity of the soil to perform its functions and to provide multiple ecosystem services. In the end, this can have a negative impact on human health, natural ecosystems and climate, as well as on our economy. The STS[26] describes the main threats to soil as erosion, decline in organic matter, local and diffuse contamination, sealing, compaction, decline in biodiversity, salinization, floods and landslides and a combination of these threats can lead to desertification. Global pressures on soils are growing, driven by economic and population growth and changing consumption patterns (EEA, 2015b). Soil resources are being over-exploited, degraded and irreversibly lost due to poor management practices, industrial activities and land-use changes (FAO and ITPS, 2015). Also climate change is an important driver for soil degradation processes (Stolte et al., 2016). It is important to recognize that soil degradation can have a transboundary dimension (Hagemann et al., 2018, in prep), and solutions for problems linked to soil degradation sometimes can be found beyond the degraded areas. Next to that, the pressures on remaining soils or on the soils of other territories increase by soil degradation[40].

5.1 Studies on soil pressures at EU level

Different studies have addressed recently the state of soil pressures and their effect on the environment. The information in this chapter is based mainly on:

- Status of the World's Soil Resources –SWSR 2015 by FAO and ITPS (FAO and ITPS, 2015)
- RECARE (Preventing and Remediating degradation of soils in Europe through Land Care) project lead by the Norwegian Institute of Bioeconomy Research NIBIO (Stolte et al, 2016)
- The state of the environment - SOER 2015 by European Environment Agency (EEA) (EEA, 2015b)

These studies focus on the soil pressures as described in Table 5.1.

The EEA states in its SOER 2015 report that the ability of soil to deliver ESS such as fertility, water and carbon storage is heavily under pressure with an even deteriorating trend in the long run (EEA, 2015b). Next to that FAO and ITPS state in their first edition of their "Status of the World's Soil Resources (SWSR)" that the majority of the world's soil resources are in only fair, poor or very poor condition. A third of the land is moderately to highly degraded due to erosion, salinisation, compaction, acidification and chemical pollution of soils (FAO and ITPS, 2015). SWSR 2015 focuses for Europe on anthropogenic degradation, i.e. alteration of soil properties induced by human activities that leads to declines in soil productivity and ecosystem services. The human activities in question include improper agricultural use, and soil disturbance and contamination due to urbanization, industrial and mining activities. Most important threats in Europe are according to SWSR2015 soil contamination, sealing and capping, soil organic matter decline, salinisation and sodification. The RECARE report gives an overview of the geographical extent of eleven soil pressures as described in the STS and in some cases also their severity and effects on soil functions. In some cases this is illustrated with a regional case study (Stolte et al., 2016).

[39] COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection
[40] http://ec.europa.eu/environment/soil/index_en.htm

Table 5.1: Soil pressures in the STS, SOER 2015 and SWSR 2015 and RECARE studies (EEA, 2015b, FAO and ITPS, 2015 and Stolte et al., 2016)

#	STS	SWSR 2015	RECARE 2016	SOER 2015
1	Erosion	Erosion by wind and water	Soil erosion by water, soil erosion by wind	Erosion
2	Decline in organic matter	Soil organic matter decline	Decline of organic matter (OM) in peat Decline of OM in minerals soils	
3	Local and diffuse contamination	Soil contamination	Soil contamination	Chemical pollution of soils
4	Sealing	Sealing and capping	Soil sealing	*(land take and urbanisation)*
5	Compaction	Compaction	Soil compaction	Compaction
6	Decline in biodiversity	Loss of soil biodiversity	Decline in soil biodiversity	
7	Salinisation	Salinisation and sodification	Soil salinisation	Salinisation
8	Floods and landslides		Flooding and landslides	
9	Desertification		Desertification	
10		Soil acidification		Acidification
11		Nutrient imbalance		
		Waterlogging*		

**Waterlogging is not described in this chapter because it is mostly associated with irrigation in Central Asian countries and therefore outside the scope of this report*

5.2 Status and trends of soil pressures

The status and trends of the threats in Table 5.1 are described in this subchapter, based on the SWRS2015 (FAO and ITPS, 2015) and RECARE (Stolte et al., 2016) studies. Table 5.2 summarizes soil pressure status trends and uncertainties in Europe and Eurasia.

1 Erosion

Jones et al. estimated in 2011 that in the 1990s 105 million ha (16 % of Europe's total land area excluding Russia) were affected by water erosion and 42 million ha (6,4%) by wind erosion. Water erosion is determined by climate and rainfall, but also by soil type, land cover and the slope of the terrain. Land cover and slope are in many cases influenced by human activity. Wind erosion is determined by the kind of soil, its cover and of course the wind.

2 Soil organic matter decline

Around 45 % of soils in Europe have low or very low organic matter content (0–2 % organic carbon). Stored carbon in soils (especially peat soils) is mainly lost by intensive and continuous arable production leading to a decline of soil organic matter and higher GHG emission, which leads to soil degradation, production losses and increased climate change. (FAO and ITPS, 2015)

3 Local and diffuse contamination

There are many locally contaminated sites in Europe, some of them are remediated, but the rate is slow. On the other hand, industrial plants are changing their processes to produce less waste and many countries have legislation to control industrial waste and prevent accidents. Diffuse soil contamination (contamination that comes from a non-point source, e.g. by atmospheric deposition, rainfall or snowmelt moving over and through soil, agricultural practices, or along (rail)roads is on the other hand a specific threat to Europe. It covers large areas, however, the real extent is not clearly know (e.g. for metallic trace elements, fertilizers, pesticides) (FAO and ITPS, 2015).

(Text continues after table).

Table 5.2: Summary of soil pressure status trends and uncertainties in Europe and Eurasia, derived from (FAO and ITPS, 2015)

Pressure to soil function	Summary	Condition*	Trend**	Confidence*** In condition	Confidence*** In trend
1. Soil erosion	Water erosion occurs mainly in cultivated mountainous and sloping areas. Due to the attention paid to this threat it is controlled in most areas, especially in the EU.	Fair	↑	+	0
2. Organic carbon loss	The loss of organic carbon is evident in most agricultural soils. Peatland drainage in northern countries also leads to rapid organic carbon loss. In Russia, large agricultural areas were abandoned which resulted in quick organic matter accumulation; however, some of these areas are now again used for agriculture.	Poor	↕	0	0
3. Contamination	Soil contamination is a widespread problem in Europe. The most frequent contaminants are heavy metals and mineral oil. The situation is improving in most regions.	Poor	↑	+	0
4. Soil sealing and land take	In densely populated Western Europe soil sealing is one of the most threatening phenomena.	Poor	↓	+	+
5. Compaction	The use of heavy machinery and overgrazing are threats in almost all the agricultural areas.	Fair	↕	0	0
6. Loss of soil biodiversity	Loss of biodiversity is expected in the most urbanized and contaminated areas of the continent. However, there are almost no qualitative estimations of the biodiversity loss in soils.	Fair	↓	-	-
7. Salinisation and sodification	Salinisation is challenging in some areas in Spain, Hungary, Turkey, and Russia.	Poor	↓	+	+
8. Floods and landslides	(not studied in SWSR 2015)				
9. Desertification	(not studied in SWSR 2015)				
10. Soil acidification	Acidification due to acid rain was a challenge in Northern and Western Europe. The situation is now improving, though several decades will be needed for complete soil recovery.	Fair	↑	0	0
11. Nutrient imbalance	In the western part of the continent the loss of nutrients is compensated by application of high doses of fertilizers. In the eastern part the use of fertilizers is insufficient, and in most soils nutrient mining results in intensive mineral weathering.	Poor	↕	0	0

* condition classes are very poor, poor, fair, good, very good
** stable = ,variable ↕, improving ↑, deteriorating ↓
*** evidence and consensus are low -, evidence and consensus are limited 0, adequate high-quality evidence and high level consensus +

4 Sealing and capping

Sealing and the loss of productive soils are especially intensive in Western Europe, due to urban sprawl and transport infrastructure. Soil sealing prevents soils from fulfilling ecological functions: fluxes of gas, water and energy are reduced; aboveground and soil biodiversity are impacted; the ability of soils to absorb water, water retention capacity and groundwater recharge are hampered which might result in damage, contamination and higher risk of floods (FAO and ITPS, 2015).

5 Compaction

Compaction is related to the use of heavy machinery and trampling of animals in agriculture. Soil compaction seriously affects soil functions and is a persistent problem of which many stakeholders are not sufficiently aware (Stolte et al., 2016). The estimates of European subsoils being highly susceptible to compaction lie between 23-36%, while 18% is already moderately affected (Jones at al., 2011).

6 Loss of soil biodiversity

Soil biodiversity is the variability of living organisms in soil and the ecological complexes of which they are part. Soils contain between a quarter to one third of all living organisms on the planet although little is known about them. Therefore it is difficult to assess the overall state of soil biodiversity. At local levels, e.g. as a result of soil sealing or contamination, it can be clear when biodiversity is declining. Decline in soil biodiversity is usually related to other deteriorations in soil quality and can be linked with other threats. Wherever soil biodiversity decline occurs it can significantly affect the soils' functions and resilience to other disturbances (Stolte et al., 2016).

7 Salinisation and sodification

Salinisation results from human interventions such as inappropriate irrigation practices, use of salt-rich irrigation water or poor drainage conditions. To flush salts from the soil, high quality irrigation water is used. (FAO and ITPS, 2015)

8 Floods and landslides

Floods and landslides are major natural hazards, resulting from a complex of natural, social, economic and ecological origins. Floods and landslides can occur as a result of climate and land use change. Landslides occur in mountainous areas and on slopes. The studies are inconclusive on whether the risk on and occurrence of floods is increasing in Europe (Stolte et al., 2016).

9 Desertification

According to the United Nations Convention to Combat Desertification (UNCCD), desertification means "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". The main processes for induced desertification are soil erosion, loss of soil fertility and long-term loss of natural or desirable vegetation. 14 million ha (8%) of the territory in southern, central and eastern Europe are very highly or highly sensitive to desertification, and over 40 million ha (23%) are moderately sensitive (Stolte et al., 2016).

10 Soil acidification

Acidification is becoming less of a problem because of the development of policies to mitigate global warming. It is expected that acidification will be concentrated in some hot spots between the Dutch and German border by 2020 (FAO and ITPS, 2015).

11 Nutrient imbalance

There is considerable (global) heterogeneity in the distribution of nutrients in soils. In Western Europe, the concentration of nutrients in soils is very high due to application of high doses of fertilizer. Doses of P and N are in some regions so high that they are at risk of contaminating the ecosystem with excessive fertilizers. In other areas (e.g. Eurasia and Central Asia) nutrient doses are much lower. In some cases this is due to natural fertility of soils, in other cases to the fact that farmers cannot afford spending on fertilizers (FAO and ITPS, 2015).

5.3 Links between soil pressures and soil functions and the European environment

The RECARE project linked the soil threats to six soil functions (Table 5.3). The soil functions can be related to several, but not all, ESS as presented in Table 3.1. In most cases there is a negative impact. In some cases there is both a positive and negative effect at the same time:

- By oxidation and mineralization of N, nutrients become available for biomass production (a positive effect) but on the other hand, when all peat is lost the underlying mineral soil is most frequently less fertile.
- Cultural heritage is negatively influenced by soil sealing, but in some cases construction work helps to discover buried records of natural or human history.
- In the short term, floods and landslides will affect biomass production negatively, whereas in the longer term (especially for landslides), this can lead to a rejuvenation of soils. (Stolte et al., 2016)

Table 5.3: Soil pressure impact on soil functions (red means negative effect, green positive) (Stolte et al., 2016)

'Soil function' from RECARE→	Biomass production	Storing/filtering/ transforming	Gene pool (biodiversity)	Physical basis	Raw materials	Cultural heritage
'Ecosystem services' relying on the function (from Table 3.1 in this report);→ Soil threat↓	Food, wood and fibre; Regulation of local climate/ temperature; Noise abatement; Air quality regulation	Water purification and soil contaminant reduction	Biochemical and pharmaceuticals; Biological control of pests and diseases	Carrying capacity for infra-structure, buildings and animals	Raw materials	Knowledge/scientific research, Cultural heritage and education
Water erosion	medium		large	large	medium	low
Wind erosion	medium	low				
SOM decline peat	low / low	large	large		low	large
SOM decline mineral	large	large	medium			
Compaction	large	large	low			
Sealing	large	large	large	large	medium	medium / low
Contamination	large	medium	large			
Salinisation	large	low	large	low		low
Desertification	large	large	large	low	low	low
Landslides and flooding	medium / low	low	low	medium	low	low
Biodiversity decline	large	large	large	large	large	large

In this subsection also the state and outlook of the European environment (SOER 2015, (EEA, 2015b)) is shortly described. SOER 2015 uses three key areas in its assessment:

- protecting the Natural Capital that supports economic prosperity and human well-being;
- stimulating resource-efficient, low-carbon economic and social development;
- safeguarding people from environmental health risks.

The trends in environmental quality that have a specific link to soil pressures (links are indicated in Figure 5.1) are briefly described in Table 5.4 and the text beneath. The topics under area "safeguarding people from environmental health risks " are left out because the soil pressures and processes leading to health risk are already described under the other areas.

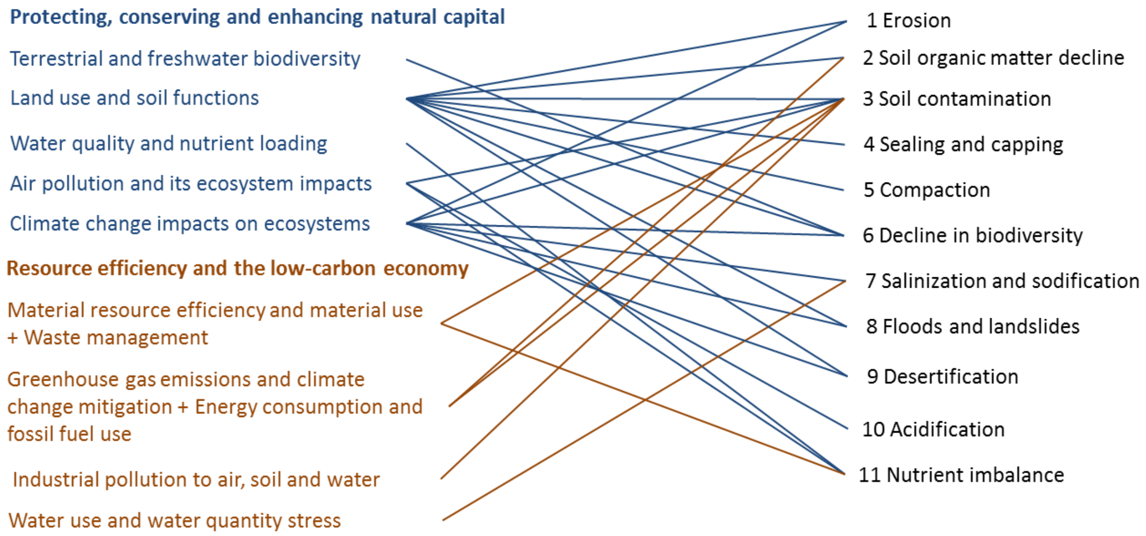


Figure 5.1: Indication of links between SOER2015 topics and soil pressures

Table 5.4: Indicative summary of environmental trends, derived from SOER 2015 *(EEA, 2015b)*

	5-10 year trends	20+ years outlook	progress to policy targets
Protecting, conserving and enhancing natural capital *			
Terrestrial and freshwater biodiversity	[red]	[red]	0
Land use and soil functions	[red]	[red]	No target
Water quality and nutrient loading	[green]	[orange]	0
Air pollution and its ecosystem impacts	[green]	[orange]	0
Climate change impacts on ecosystems	[red]	[red]	No target
Resource efficiency and the low-carbon economy **			
Material resource efficiency and material use	[orange]	[orange]	No target
Waste management	[green]	[orange]	0
Greenhouse gas emissions and climate change mitigation	[green]	[red]	V/X
Energy consumption and fossil fuel use	[green]	[red]	V
Industrial pollution to air, soil and water	[green]	[orange]	0
Water use and water quantity stress	[orange]	[orange]	X

* "ecological status of freshwater bodies" and "marine and coastal biodiversity" are left out because of weak link with soil
** "transport demand and related environmental impacts" is left out because of weak link with soils

Indicative assessment of trends and outlook		Indicative assessment of progress to policy targets	
[red]	deteriorating trends dominate	X	largely not on track to achieving key policy targets
[orange]	trends show mixed picture	0	partially on track to achieving key policy targets
[green]	improving trends dominate	V	largely on track to achieving key policy targets

Protecting, conserving and enhancing natural capital
Europe's natural capital is not being protected, conserved and enhanced as required. This leads to biodiversity loss, loss of soil functions and land degradation. Climate change remains a major concern and its impacts are even projected to intensify.

Terrestrial and freshwater biodiversity

Much is still unknown about the status of European biodiversity and how it relates to ecosystem functioning and the long term delivery of ESS. This certainly applies to soil biodiversity in specific. Biodiversity continues to be lost, mainly due to pressures caused by human activities: (semi)natural habitats are affected by urban sprawl, agricultural intensification, intensively managed forests, overexploitation of natural resources and increasing impacts from climate change. Although no specification was made for soil biodiversity, we may assume that the negative trend is the same.

Land use and soil functions

Land use is a major factor influencing the distribution and functioning of ecosystems and thus the delivery of ecosystem services. Ecosystems and their services can deteriorate by degradation, fragmentation and unsustainable use of land. Loss of soil functions due to urban land take and land degradation (e.g. soil erosion or land intensification) is continuing. Nearly a third of Europe's landscape is highly fragmented and it is not expected to improve in the long run. Main effects are e.g. a lower provision of several key ecosystem services, threatened biodiversity, increased vulnerability to climate change and natural disasters and exacerbated soil degradation and desertification.

Water quality and nutrient loading

This topic covers the status of water quality which is influenced by the quality of agricultural soil and by nutrient imbalances. Nutrient concentrations in many places are still high which affects the status of water. In the long term, diffuse pollution in regions with intense agriculture production will still be high, resulting in continued eutrophication problems.

Air pollution and its ecosystem impacts

Air pollution harms both human and ecosystem health. It contributes to eutrophication and the acidification of water and soil. It also impacts agricultural production and forests, causing yield losses. Although lower emissions will contribute to fewer exceeding of acidification and eutrophication limits, long term problems from eutrophication are forecast to persist in some areas. Adverse impacts caused by acidification will nevertheless improve a lot.

Climate change impacts on ecosystems

Climate change is expected to increase and have more severe effects on ecosystem functioning. Climate change (extreme events like storms, heavy rainfalls and drought) increases soil degradation, and degradation in return impacts climate change (through GHG emission). Soils can be used in climate change adaptation but information is often lacking on the costs and benefits of adaptation.

Resource efficiency and the low-carbon economy
Short-term trends in this area are encouraging less use of fossil fuels and lower emissions of pollutants. However, in the longer term pressures remain considerable and the European economic system remains intensive in its use of resources and water.

Material resource efficiency, material use and waste management

Although improvements have been made, in the longer term, economic growth can increase resource use. For soil this includes e.g. nutrients, organic matter and carbon, water and mineral resources including fossil fuels. The notion of a circular economy boosts resource efficiency. Waste prevention, reuse and recycling reduce the demand for resources and mitigate energy use and environmental impacts. Although in the short term less waste is being landfilled, the total waste generation will most likely remain high in the longer term.

Greenhouse gas emissions, climate change mitigation, energy consumption and fossil fuel use

GHG emissions have decreased in the short term, but policies are expected to be insufficient to reach the 2050 decarbonisation target. There is a link with soil through the impact of agricultural (and water management) practices, the energy sector (fossil fuels) and carbon capture and storage. Renewable energy (including soil energy) will increase substantially, although fossil fuels continue to dominate EU energy production in the long run. Energy production is responsible for considerable harm to the environment and human well-being.

Industrial pollution to air, soil and water

Industrial emissions are expected to decrease but will continue to harm the environment and human health considerably. Endocrine and newly emerging contaminants are of growing concern. Chemicals can have long lasting impacts, especially persistent and bio-accumulative chemicals. Pollutants put pressure on the soil's capacity to deliver ecosystem services.

Water use and water quantity stress

Water use for different purposes is decreasing in most sectors and regions but agricultural water use remains a problem especially in southern Europe. Impacts of climate change can even deteriorate this in the longer term and also threaten soil functions. Overexploitation of groundwater can put the soil-water-sediment system under further pressure, leading to droughts and salinisation.

6 Impact of land- and soil management practices on soil ecosystem services

Land use and management decisions have a strong impact on urban, agricultural and forest ecosystems and their components, which in turn have a substantial influence on the supply of ESS. The European Commission established a Reference Scenario to assess the impact of energy and climate policy up to 2050. Under this scenario, economic growth and population changes stimulate urban and industrial expansion (Maes et al., 2015a). Arable land and pasture are expected to decrease while the proportion of arable land used for cultivation of new energy crops will increase. Forest cover will grow in response to increased demand for energy from biomass, partially at the cost of semi-natural areas, and due to land abandonment.

In this chapter, the impact of the main land management practices will be described for urban, agricultural and forest systems separately because priorities and opportunities for optimizing land management differ. Besides, these systems are managed by different stakeholders. Cooperation between private and public stakeholders is required to achieve sustainable use of soil ecosystem services. Land is often owned by private parties while different stakeholders rely on the services. It is a challenge for policy makers to develop instruments that help to find a better balance between land owners' needs and societal benefits.

6.1 Urban soil management practices

We discuss here several land management and soil management practices that may enhance ESS related to soil. Most practices are aimed at preventing loss of ESS that are directly or indirectly related to soil.

Measures to reduce soil sealing by buildings and infrastructure
To prevent soil sealing and its adverse impact on soil ecosystem services, the 'Guidelines on best practice to limit, mitigate or compensate soil sealing' (Prokop et al., 2011) suggest three levels of measures: 1) measures to limit soil sealing; 2) mitigating measures to maintain ecosystem services; 3) measures to compensate for sealing when on-site mitigation measures are insufficient. The guidelines include spatial planning measures to limit soil sealing, economic incentives to encourage or regulate soil sealing, and technological measures to limit and mitigate soil sealing by e.g. permeable pavements (Figure 6.1), sustainable buildings and water harvesting.

Figure 6.1: Permeable pavement can be applied to reduce the sealing grade of areas that need to be paved due their function (picture from EEA, 2016a).

Buildings and infrastructure cover soil resulting in a loss of soil functioning that is close to irreversible (EC, 2012). Measures to prevent soil sealing will enable preservation of soil ecosystem services.

Measures to reduce compaction

Soil compaction can be caused by intense use of urban areas, highly visited green spaces and traffic. Taking measures to prevent compaction will be aimed at preventing loss of soil ecosystem services. Besides managing the activities that cause compaction, there are technical measures that can limit the compaction as a result of intensive use. In some parks in the city of Utrecht, the Netherlands, a product consisting of artificial turf (grass) and special substrates have been applied to mitigate the compaction effect of intensive recreational use (Van der Meulen et al., 2016).

Management of man induced soil subsidence

In many coastal and delta cities in the world land subsidence exceeds absolute sea level rise (GFDRR, 2016). Subsidence is caused by natural and anthropogenic causes. Man induced subsidence in the form of compression of shallow subsurface layers is caused by loading (with buildings), or as a result of drainage and subsequent oxidation and consolidation of organic soils and peat (Figure 6.2). In deeper layers subsidence may be caused by extraction of resources such as oil, gas, coal, salt and groundwater.

Figure 6.2: Retaining high water levels in peat areas avoids oxidation and subsidence

Measures to prevent or manage subsidence may support the water regulation and fresh water provision services. To prevent subsidence, insight in the impact of extractions and building activities is needed in order to manage them with minimal impact. Restriction of groundwater extraction is of major importance if that is causing subsidence. Recovery, however, takes time and artificial groundwater recharge may be useful to speed up recovery of groundwater levels. Using the right building techniques and materials that suit local geological conditions will minimize compression.

Prevention and remediation of contamination and salinisation

Prevention and remediation of soil contamination help to maintain and restore the soils' capacity to provide ESS. Prevention measures may include policy, regulation or technical measures such as the use of physical barriers between contaminants and soil. Remediation may restore the quality of soil and groundwater to a large extent but in many cases residual contamination may remain. Therefore, also in this case, prevention is crucial for preserving the soil's capacity to deliver ESS.

Soil microorganisms provide major potential for degrading contaminants such as chlorinated solvents, aromatic hydrocarbons and pesticides. Their activity may be enhanced to optimize the degradation of contaminants. When pollutants are toxic to microorganisms, the water purification service of the soil may be damaged.

Salinisation occurs as a result of natural processes and can be amplified by human activities such as groundwater extraction and ATES (as a result of mixing fresh and brackish groundwater). Impact of groundwater extracting and mixing activities on groundwater quality should be well understood and managed. Avoiding salinisation retains provisioning ESS such as fresh water provision, crop production (however, a reaction on salinisation might be to convert to salt resistant crops), regulating services such as water purification and soil contamination reduction and cultural services (archaeology).

Maintaining or increasing carbon storage in urban soils
Excavation of topsoil and soil sealing have an adverse effect on soil carbon storage (EEA, 2016b). Minimizing these activities can contribute to the preservation of soil ESS that are impacted by a reduction of organic carbon (OC) content. Different soil management practices result in differences in the OC stock in vegetated soils in residential areas and in non-residential areas. Soil OC stocks in residential green areas are higher, possibly as a result of input of compost, mulches or organic fertilizers. When comparing urban soils to regional arable soil, it seems that urban soils store more OC (20.2 kg/m^2) than arable soils (14.3 kg/m^2) at equivalent depths. OC content in the top 20 cm is comparable to values from literature for temperate grassland worldwide (42% versus 41%). However, when taking into account the assumed zero stock under buildings and the lost OC by excavation under impervious surfaces, the overall OC storage in urban soils and arable land is equal (14.5 versus 14.3 kg/m^2) This research by Edmondson et al. (2012) demonstrates the impact of excavation of the first meter of urban soil and gives rise to the idea that the pattern of sealed and unsealed surfaces may be important for the impact of sealing on OC storage in urban soils.

6.2 Agricultural management practices

Conservation agriculture
Compared to conventional agriculture, conservation agriculture induces beneficial changes in soil properties and processes which favor the delivery of multiple soil ecosystem services (Palm et al., 2014). The three main pillars of conservation agriculture are tillage reduction, soil cover maintenance and crop rotations.

Tillage reduction
The use of any method of soil cultivation that leaves the previous year's crop residue on fields before and after planting the next crop has been proposed as an alternative to traditional tillage (Figure 7.18 *left*). The reduction in tillage intensity increases carbon sequestration and soil biodiversity. The build-up of soil organic matter provides food stock for microorganisms favouring microbial growth (Venter et al., 2016). Conservation tillage is also influencing water regulation through the increase in soil water infiltration which in turn fosters groundwater storage and lessens surface runoff.

Figure 6.3: (Left) Mouldboard ploughing used as primary tillage operation in conventional agriculture. (Right) Non-tilled soil showing crop residues and biological activity (i.e. earthworm casts) on the soil surface.

Crop residue management

The maintenance of crop residues on the soil surface constitutes the second major component of conservation agriculture (Figure 6.3 right). This practice increases the provisioning of food and fibre through the control on water regulation. The maintenance of crop residues decreases soil water loss reducing evaporation and in some cases the allelopathic effect can prevent weed germination (Fenwick et al., 1983). Furthermore, the crop residue cover protects soil from water and wind erosion and favours carbon sequestration (Poeplau and Don, 2015). Crop residue management and tillage system effects on some soil functions and ecosystem services are presented in Table 6.1.

Crop rotations

Crop diversification through crop rotations, cover crops or intercropping favour regulation and maintenance services by facilitating the control of pests, weeds and diseases, minimizing and even avoiding the use of agrochemicals (Duru et al., 2015). Furthermore, crop diversification stimulates soil microbial abundance and, in turn, soil biodiversity. The diversification of cereal-based cropping systems with legumes is seen as a promising strategy to increase carbon sequestration and to provide additional ecosystem services while reducing the reliance on synthetic fertilizers (Jensen et al., 2012).

In summary, the adoption of conservation agriculture in croplands favours different ESS. In particular, carbon sequestration, water regulation food and fibre provision and biological control of pests and diseases. In Europe, there are about 2.3 Mha of arable cropland under conservation agriculture systems, mainly in Spain, France, Finland, UK, Italy, Portugal and Switzerland, and 1.8 Mha in woody crops. The adoption of conservation agriculture is expected to grow in the future in response to increasing energy and input costs (González-Sánchez et al., 2016). Apart from the reduction of fuel, labour and machinery costs, it will be beneficial for the increase of soil ecosystem services.

Table 6.1. Impacts of soil management on some soil functions and ecosystem services (adapted from Stavi et al., 2016).

Soil function/ ecosystem service	Soil tillage system			Crop residue management		
	Conventional (intensive)	Moderated (reduced)	No-tillage	Entire removal	Moderate removal	No removal
Water availability for crops	**	**	**	*	**	***
Weed control	***	***	*	*	**	***
Insect and pathogens control	***	***	*	***	**	*
Soil quality	*	**	***	*	**	***
Soil erosion control	*	**	***	*	**	***
Soil organic carbon pool	*	**	***	*	**	***
Environmental pollution control	**	**	**	**	**	**
Greenhouse gas mitigation	*	**	**	**	**	**
Crop yield productivity	**	***	**	**	**	**

*, **, *** Low, medium and high impact, respectively.

Water management

Practices to increase soil water infiltration

The condition of the soil surface is key for the partition of precipitation into infiltration and runoff, which in turn conditions the groundwater storage and the chances of fast floods. Soil physical properties such as water infiltration, porosity and structure rely on adequate tillage and farming practices. In particular, soil water infiltration is reduced by soil compaction resulting from a number of harmful agricultural practices. The voluntary guidelines for sustainable soil management suggest practices to prevent and mitigate soil compaction: avoiding heavy tillage and heavy machinery traffic, the use of crops with strong roots that are able to break up compacted soils and the improvement of the soil organic matter and soil biodiversity. To improve infiltration and avoid surface runoff, management of the soil cover is another practice (FAO, 2017).

Practices to decrease groundwater pollution

A sufficiently long interaction between groundwater and an adequate geological substrate results in water purification for fresh water provision (even natural sparkling water). However, this process is negatively affected by the input of chemical and biological substances resulting from agricultural activities, animal farming, rangeland and forestry and industrial pollution (Figure 6.4). These substances can range from simple inorganic molecules acting as crop fertilizers to complex organic molecules such as biocides. Biological inputs can include sludge, manure, vegetal residues or microorganisms.

Introducing vegetative filter strips in agricultural areas can significantly reduce the concentration of pathogens at the intake of treatment plants (Bergion et al., 2017). The soil can retain chemicals and make them available to plants as fertilizers, and can transform biological input into soil organic matter. On the other hand, the oxidation of soil organic matter will release mineral nutrients, which can be eventually leached to water bodies. Persistent organic pollutants will have negative long-term effects on groundwater, limiting its usability and therefore the delivery of ecosystem services.

The provision of fresh water, water purification and water regulation rely on adequate soil and land management practices. Controlling the leaching of pollutants to water bodies requires adequate management of animal farming and crop residues, fertilization and soil organic management dynamics. These are key management aspects to reverse a trend that has been accelerated by the economic development of the past century. The Oudon River basin, in northwest France, exemplifies these processes. Intensive agricultural activities in the basin have led to nitrogen, phosphorus and pesticide pollution in the river since the 1980s. The simulation models applied to screen land management alternatives found that soil properties and the crop sequence were key to reduce pollution. River nitrate flow was reduced by 8% with filter strips, 11% with catch crops, and 15% with reduced fertilization. On the other hand, the conversion of temporary pastures to cereals and rapeseed increased the nitrate flow by 18% (Laurent and Ruellant, 2011).

Figure 6.4: Left: Maize is a high yielding crop requiring large amounts of agrochemicals. Right: Irrigation return flows convey fertilizers and other agrochemicals.

Grazing management

In grazing systems, a sufficient cover of growing plants should be maintained to protect the soil from trampling and erosion; livestock management should take into account grazing intensity and timing, animal types and stocking rates (FAO, 2017). Grazing can have a strong impact on soil conservation and ecosystem services (Papanastasis et al., 2017). Overgrazing affects negatively soil vegetative covers, reducing the protection of soil surface making it more susceptible to soil compaction and crusting. This mismanagement usually leads to a loss of soil organic matter, resulting in the emission of greenhouse gases to the atmosphere, and an increase of wind and water erosion (Delgado et al. 2013). Concomitantly, the capacity of the farming system to produce feed can be severely reduced.

Landscape structuring

Highly intensified landscapes frequently provide high levels of provisioning soil ecosystem services at the expense of low levels of supporting and regulating services. In many parts of the world, agricultural landscapes are losing complexity, causing a decline in soil biodiversity, which leads to reductions in ESS on which agriculture depends (Landis, 2017). The European landscape varies from extremely simple and structurally poor landscapes (>95% annual crops) to complex and structurally rich ones with up to 50% non-crop habitats (such as field margins, hedges, grassland, woods, etc.) (Thies et al., 2003). Simplification of landscapes causes limitations in water quantity and quality or the loss of biodiversity. This should be avoided and can be counteracted by landscape management and through the implementation of agri-environmental schemes. Figure 6.5 shows the steppe landscape of Monegros (Spain). The left picture shows the traditional complex structure with Juniperus thurifera patches between the cereal fields. The right picture shows a simple structure after agricultural intensification (e.g. repeated tillage operations) with loss of soil biodiversity and water retention and increase of soil erosion.

Figure 6.5: Effects of landscape structuring in the steppe landscape of Monegros (Zaragoza, NE Spain)

Terracing

A prominent role of terracing is erosion control, runoff reduction, biomass accumulation, soil water recharge, and nutrient enhancement (Wei et al. 2016). The cessation of activities of terrace maintenance and the development of scrubland vegetation poses serious threats, including the potential for large-scale fires, the loss of soil through run-off erosion, and landslides caused by the progressive collapse of the terraces. This is the case with the terraced landscape in Sistelo (Portugal; see Figure 6.6). Considering the consequences associated with current abandonment trends, the European Union and the national government implemented several measures to encourage agricultural practices and animal husbandry.

Figure 6.6: The collapsing agricultural terraces of Sistelo (Portugal).

6.3 Forest management practices

The ability of woodlands and forests to provide soil ecosystem services depends on the type of management and the location of wooded patches in the landscape. Trees rely on soil for anchorage, nutrients and water. Apart from carbon sequestration, forests protect soils from both wind and water erosion, preventing landslides and, consequently, allowing the provision of clean water and a balanced water cycle. Furthermore, trees play an important role in the creation of new soil, through the rotting and decomposition of leaves and other vegetal residues. Soil formation involves changes in the physical, chemical and biological properties of the soil over decades, centuries and even millennia.

The amount of wood extracted from a forest determines the rate at which biomass accumulates and, therefore, the amount of carbon stored in forest biomass and soil (Eggers et al., 2008). Harvesting of forest biomass causes the largest change in soil quality in the temperate and boreal region (Hansen et al., 2011), with a significant decrease in the soil content of almost all nutrients and an increase in soil acidification depending on the mineral composition of the soil and the kind and intensity of biomass removal. Changes in tree species might accelerate the negative nutrient balance and soil acidification due to increased deposition of air pollutant compounds. Modern intensive forestry includes heavy machine trafficking with negative effects on soil macroporosity (a macropore volume <10% restricts root growth). On steep slopes clear-cut or intensive harvesting can induce soil losses by erosion (Hansen et al., 2011).

Agroforestry is a land-use system where woody perennials (trees, shrubs, etc.) are deliberately used together with agricultural crops and/or animals on the same land-management unit[41]. Agroforestry has been proposed as a sustainable land management practice over conventional agriculture and forestry, conserving biodiversity and enhancing ESS provision without compromising productivity (Jose, 2009). Agroforestry supports high levels of biodiversity and ecosystem goods and services such as soil erosion control, soil fertility, nutrient cycling and food, timber and biomass production (Torralba et al., 2016). In Atlantic and Continental Europe, intercropping in chestnut and walnut systems or integrating trees in arable systems, can increase soil fertility and enhance biodiversity whilst maintaining agricultural productivity. In Mediterranean Europe, integrating cover crops and/or grazed legumes in vineyards and olive monoculture plantations generally increases soil fertility and nutrient retention whilst reducing soil losses (Torralba et al., 2016).

According to recent estimates, the total area under agroforestry in the EU 27 is about 15.4 Mha which is equivalent to about 9% of the utilised agricultural area of the EU (den Herder et al., 2016). Considering these figures, European agroforestry should hold a more prominent place on the policy agendas.

[41] http://www.fao.org/forestry/agroforestry/80338/en/

7 Exploration of valuation and monetization options

The Economics of Land Degradation (ELD) Initiative highlights the value of sustainable land management and provides a global approach for the analysis of the economics of land degradation. It aims to make economics of land degradation an integral part of policy strategies and decision making by increasing the political and public awareness of the costs and benefits of land and land-based ecosystems. Global estimates of degraded areas amount to at least 10-20% of land usable for production, with an estimated total economic loss of 40 billion USD per year (ELD, 2013).

In another global assessment of the cost of land degradation across both temperate and tropical zones, it is reported that the annual costs of land degradation due to land use and land cover change amount to about 231 billion USD per year (Nkonya et al. (2016). More than half of these costs are due to losses suffered by non-local stakeholders; particularly, these 'external' losses involve carbon sequestration, biodiversity, genetic information and cultural ecosystem services. However, the ESS they consider are rather roughly valuated while the indirect analysis was not strictly related to soils. Their estimation only provides a general orientation and an order of magnitude.

The above examples shows that sustainable land management and ecosystem services have a value. Economic valuation can demonstrate the importance of ESS for human well-being, and can be used in land-use decision-making. Without (non-market) valuation, only a small share of the relevant effects are usually accounted for in decision-making processes, since many ESS are public goods and the use of ecosystems can be a source of externalities. They influence human well-being in less obvious and direct ways; preferences for them may not be well defined. Economic valuation helps to uncover these effects.

The economic valuation of soils and its ecosystem services is a relatively new and still not well developed area of research, even though first attempts in this context can be traced back to the 1960's (Baveye et al., 2016). Both theoretical–conceptual and empirical papers are scarce. When it comes to application, i.e. empirical studies trying to estimate the economic value of soil ecosystem services, the situation is rather precarious, as suggested by a number of recently published review articles (Adhikari and Nadella, 2011; Baveye et al., 2016; Jónsson and Davíðsdóttir, 2016; Prado et al., 2016; Robinson et al., 2014).

7.1 Methods used in economic valuation

Economic valuation of ESS is based on the preferences people have for these services. Generally, value can be expressed on different scales, from qualitative to monetary. Monetization is not always an option – for example, when system complexity and/or the plurality of values involved are high as is the case for soil ESS (Figure 7.1). Value is not a constant and generic figure: it depends on the abundance of an ESS, the demand for the ESS and technological and natural alternatives. It also differs between stakeholders and at spatial and temporal scales.

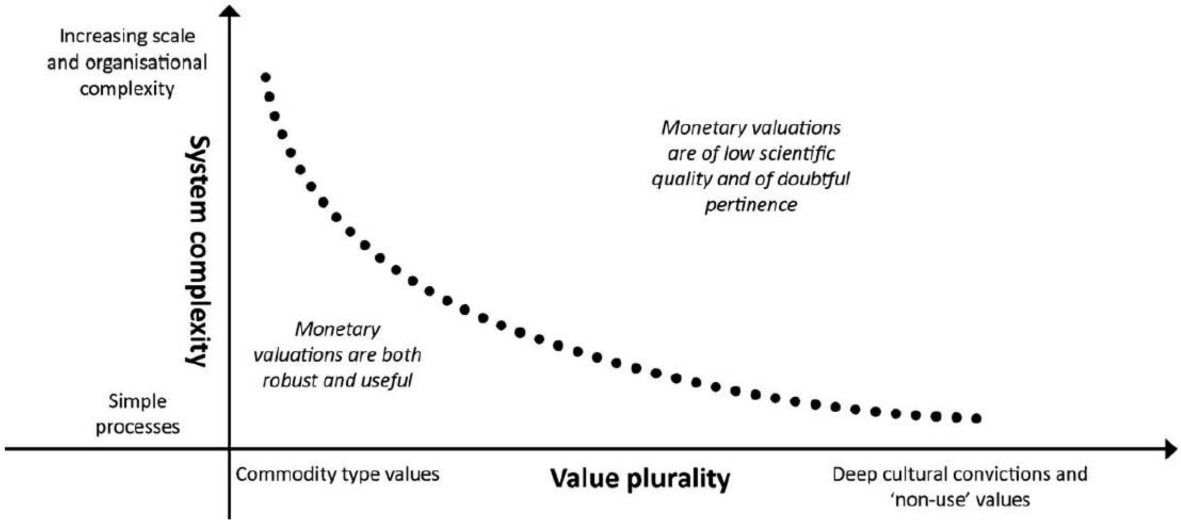


Figure 7.1: Applicability of monetary valuation as depending from system complexity and degree of value plurality involved (Frame and O'Connor 2011).

To assess the economic impact of change in land and soil management, it is first required to identify impacted ESS and to quantify the change in their (potential) provision. Only then can the change be expressed in terms of economic value (Figure 7.2). Thus, economic valuation is a multi-stage interdisciplinary exercise.

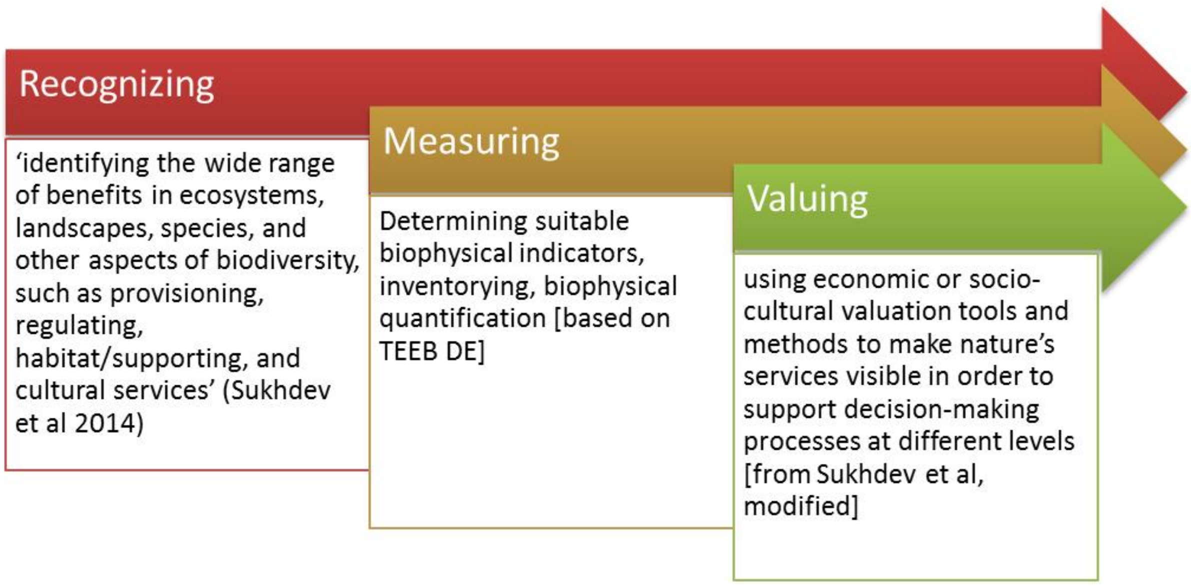


Figure 7.2: The valuation cascade from recognition and identification, through (biophysical) measurement to (economic) valuation (based on Sukhdev et al. 2014 and Natural Capital Germany – TEEB DE 2017).

Different methods can be used in economic valuation (Table 7.1)[42] depending on the specific ecosystem service(s) considered and on the purpose of the valuation exercise, which can range from general information through cost-benefit analysis to economic accounting (Costanza et al. 2014).

Table 7.1: Three classes of valuation methods can be distinguished that can be used to estimate economic values for non-market ecosystem services.

Valuation method class	Description
Cost-based methods	Costs of replacing/restoring/avoiding loss of a given ecosystem service are used as proxy of its economic value. This is the simplest method class with low data demands. It is mostly applied to estimate economic value of regulating ecosystem services. These methods are incompatible with economic welfare theory *Example*: The cost of nitrogen fertilizer can be used as proxy for the economic value of nitrogen retention by soils.
Revealed preference methods	These methods use the contribution of ecosystem properties to the demand for proxy goods (especially: tourism [travel cost method] and real estate [hedonic pricing]) as estimated by means of statistical models. These methods have high data demands and are applicable for ecosystem properties/services that can be linked to marketed goods (especially cultural and regulating ecosystem services). *Example*: The disentanglement of different factors contributing to (differences in) land prices, including various soil characteristics as proxy for the value of these characteristics and the related ecosystem services.
Stated preference methods	These methods use questionnaire-based elicitation of willingness-to-pay for hypothetical ecosystem changes (standard approaches: contingent valuation and choice experiments). They are highly flexible but prone to psychological biases. They are potentially applicable to all types of ecosystem services. These methods are the only method class that is capable of capturing non-use values. *Example*: The willingness of residents of a given area to pay for a soil erosion prevention programme.

In existing soil valuation studies different methods have been applied. A summary based on the data from Jónsson and Davíðsdóttir (2016) is provided in Figure 7.3.

[42] Another popular valuation approach is benefit transfer, i.e. the use of estimates from other studies, adapted to one's own study area. On the potential and challenges of benefit transfer, see Spash and Vatn (2006) and Schmidt et al. (2016).

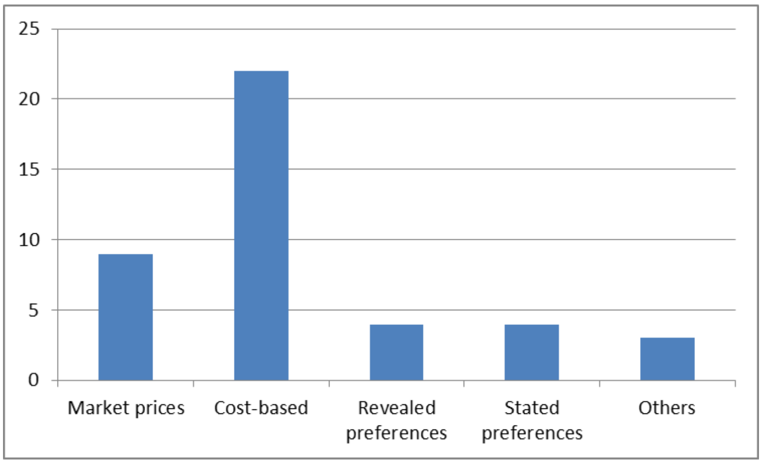


Figure 7.3: Application of different valuation methods in soil valuation studies analysed by Jónsson and Davíðsdóttir (2016)

Most studies used market price proxies or cost-based methods to estimate the economic value of soil ecosystem services. Both approaches have limits – as mentioned above-; cost-based methods are easy to use but inconsistent with economic theory; market price proxies are also problematic, as when, e.g., the price of top soil is used as a proxy for the value of provisioning services provided by soils. In most cases, the market good (e.g. top soil) is not equivalent to any soil ecosystem services, so its price is only a rough proxy. Moreover, market prices are usually distorted due to taxes, subsidies, imperfect market structures etc. Thus, such approaches can be helpful as a first estimate, but their informational quality is limited in most cases.

Theoretically, land prices should reflect, among other factors such as proximity to public infrastructure, the value of soil ecosystem services, at least those that directly benefit land-owners. Thus, 'one would think that it would be feasible to disaggregate land prices into the prices of the various below- and above ground components of land, and eventually to estimate the monetary value of soils' (Baveye et al., 2016). As it turns out, however, the actual disentanglement of the relevant factors, e.g. by means of hedonic pricing, is anything but straightforward and simple. For a rare instance of such a hedonic pricing analysis of land prices, see, e.g. Samarasinghe and Greenhalghe (2013), who used a hedonic pricing model to determine the influence of inherent characteristics of soils on farmland prices in New Zealand. Their results show that climatic topographical geographical locational land use and size attribute to determining the value of rural farmland values. In many cases it is a combination of soil characteristic that adds value to a soil (e.g. well-drained soil and soil that provides sufficient water to crops).

7.2 The value of soil ecosystem services

7.2.1 The value of provisioning services

The economic value of some provisioning ESS from the soil, such as selected raw materials, can be approximated by market prices (Jónsson and Davíðsdóttir 2016). For most provisioning ESS, this is however not possible because it would be actually necessary to disentangle the relative contribution of soil to the market price. In a similar vein, to give a rough impression of the commercial value of soil-related commodities, Robinson et al. (2014) collected data on the market prices of bulk topsoil across the globe (for Europe: UK and Iceland). They found median prices of around 22 USD per metric ton in the US and Canada versus ca. 47 USD per ton in the UK. They also presented back-of-the-envelope calculations of replacement-cost based values of different soil properties, such as raw materials (sand, clay), water provision and nutrients (Figure 7.4; mainly UK).

	Commodity price per ton	T/ha to 30 cm	Cost, 30 cm of topsoil/ha
Sand Wanlip sand and gravel, Leicester, UK	£ 17.38	1560	£ 27,113 $ 42,025
Silt/Clay mix Cardigan sand and gravel, Cardigan, UK	£ 7.33	2340	£ 17,152 $ 26,586
Carbon Stern review	£ 150.00	107.25	£ 16,088 $ 24,936
Nutrients (NPK) Representative price Feb 2013 Dairy Co market information	£ 350	2	£ 700 $ 1085
Water ($25 m^3 m^{-3}$) Utility retail price metered m^3	£ 1.57	750	£ 1178 $ 1826
Worms (USA) Red worm composting blog Lowest retail price ($15/lb) Range ($15–40)	£ 4300	2	£ 8600 $ 13,300
Reconstituted topsoil		Total	£ 70,830 $ 109,787
Bulk recycled screened topsoil, Wanlip sand and gravel, Leicester, UK	£ 10	3900	£ 39,000 $ 60,450
Bulk topsoil Median UK price (Fig. 3)	£ 30.38	3900	£ 118,482 $ 183,647
Retail topsoil premium grade $1 m^3$/~1 ton, Rolawn loam topsoil, Tesco.com	£ 100	3900	£ 390,000 $ 604,500

† Soil bulk density assumed to be ~$1.36 g/cm^3$ (Loam: 40% sand 60% clay and silt); prices exclude taxes; conversion to USD uses exchange rate of 1.55 for 2013.

Figure 7.4: Back-of-the-envelope calculations of the value of soil-related commodities in UK (unless otherwise stated). Source: Robinson et al. 2014

According to the literature review by Jónsson and Davíðsdóttir (2016), the range of the values for ‘biomass production’ is between around 230 and more than 22,000 USD per ha per year, depending i.e. on the crop or farming system; for ‘raw materials’ (topsoil, clay, peat) the range is 9–147 USD per tonne. Generally, the economic valuation of provisioning ESS related to soils is rather trivial, as often market prices can be used, at least as a very rough approximation.

The only studies that estimated the economic value of carrying capacity for infrastructure, buildings and animals are Dominati et al (2014a; 2014b). Using various methods from the cost-based methods class, they arrived at values ranging from 32 to 110 international dollars (id) per hectare per year.

The contribution of soils to fresh water provision can be valued by means of the replacement cost method – how much does it cost to clean water for drinking (if cleaning is not ‘done’ by soils)? This approach, however, has not been applied in Europe. Another possible approach, chosen for instance by Dominati et al. (2014a, 2014b), is to look at nutrient retention by soils more directly, and value it by means of methods such as provision costs and defensive expenditures (avoidance costs): available estimated values range between 540 and 6400 id per hectare per year (Jónsson and Davíðsdóttir 2016).

For other provisioning services, no applicable values were found.

7.2.2 The value of regulation and maintenance services

Arguably the most comprehensive economic valuations of soil ecosystem services were conducted by Dominati and colleagues in New Zealand (Dominati et al., 2016, 2014a, 2014b). Using predominantly cost-based valuation methods, they analysed a number of soil ecosystem services in different landscapes, including agricultural production, support of animals and infrastructure, flood mitigation, nutrient cycling, climate regulation, pest regulation. Dominati et al. (2014b) found that nutrient cycling and flood mitigation are responsible for the largest share of the total economic value of soils. In a pastoral agriculture landscape in New Zealand, Dominati et al. (2014a) found that the value of regulating soil services is about 2.5 times as high as that of soil provisioning services. In this case, the services with the highest value were the filtering of nutrients and contaminants (58–63% of total value, regulating services), followed by the provision of food and then flood mitigation, again a regulating service. A similarly comprehensive approach can be found in Porter et al. (2009) and Sandhu et al. (2008), who included a number of soil ecosystem services (nitrogen regulation, soil formation, soil carbon, hydrological flow) in their comparisons of different types of agriculture in Denmark and New Zealand, respectively.

Carbon sequestration in soils can be valued relatively easily on the basis of the various estimates of social cost of carbon (SCC) available in the climate economics literature (van den Bergh and Botzen, 2015). SCC estimates are usually generated by means of integrated assessment models (IAM). These estimates are very sensitive to a number of parameters in these models. This is especially the case of the so-called damage function, which links temperature increases to losses in terms of capital, production, human lives etc., and the social rate of discount, which enticed a huge and controversial literature of its own (Arrow et al., 2014). As a result, SCC estimates vary in the range of orders of magnitude[43] (van den Bergh and Botzen, 2015) and it is by no means clear which estimate to use when valuing, e.g., carbon storage by soils.

An alternative to the use of SCC estimates is the approach by Rodríguez-Entrena et al. (2012), who conducted a choice experiment to evaluate the demand for carbon sequestration in olive grove soils in Andalusia (Spain) and came up with a willingness to pay by the general public of 17 € per ton CO_2 per person. Another study worth noting in this context is Noe et al. (2016), who used a Monte Carlo analysis[44] to identify the value of carbon storage in Minnesota prairies; they found an average value of 73 USD per ha per year. In another study, Jerath et al. (2016) estimated the economic value of carbon storage in the Everglades (US), showing that carbon storage in soils amounts to between 77 and 90 per cent of the overall value across study sites.

For other regulation and maintenance services, no applicable values were found.

7.2.3 The value of cultural services

In contrast to provisioning services that can be assessed through market prices, cultural ESS are to be assessed through alternative, often non-monetary assessment methods which makes it more vulnerable in decision making processes (Chan et al. 2012). Valuation studies of soil cultural ecosystem services are scarce; the only one cited by Jónsson and Davíðsdóttir (2016) in their comprehensive literature review is one by Eastwood et al. (2000), who estimated the economic cost of soil erosion in terms of recreational loss in New Zealand. They estimated the soil-erosion related expenditures of public authorities to enhance touristic areas of more than 550,000 id per year.

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[43] Depending on the model used, parameter specifications etc., van den Bergh and Botzen (2015) find mean values ranging from 6 USD per tonne to almost 150 USD per tonne, only for the three most common models DICE, FUND and PAGE.

[44] The Monte Carlo analysis is a statistical tool used to deal with broad and uncertain ranges of values of modelling parameters.

7.3 Selected insights from economic valuation studies of soil ecosystem services

Of the 33 soil valuation studies included in the review by Jónsson and Davíðsdóttir (2016), only five were conducted in Europe (see Figure 7.5). Furthermore, they found that virtually all economic valuation studies of soil ecosystem services focus on agricultural contexts. This indicates significant potential for new research in this area.

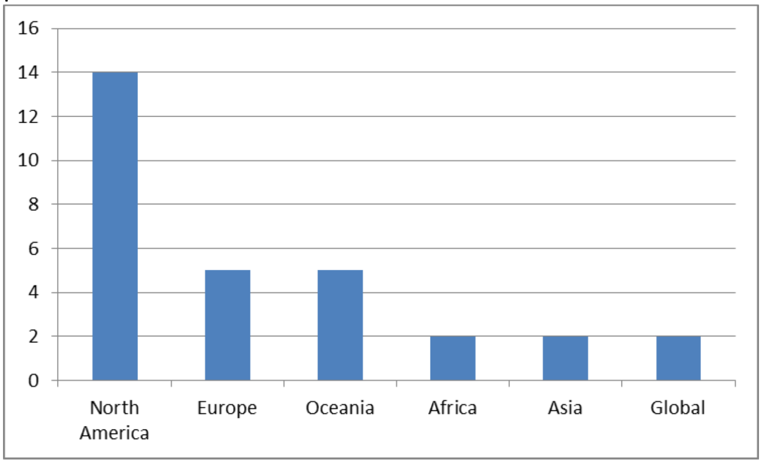

Figure 7.5: Distribution of economic valuation studies of soil ESS according to Jónsson and Davíðsdóttir (2016)

Since this report's focus is on the ESS provided by soils *in Europe*, the relevance of most existing valuation studies is limited for its purposes. However, the main limitation is that the specific values estimated in non-European studies cannot be easily transferred to European context; thus, the focus here is mainly on approaches, methods and orders of magnitude or relative importance of different soil ecosystem services.

Most existing economic valuation studies of soil ecosystem services focused on a narrow selection of ecosystem services and valuation methods (de Groot et al., 2012). A summary of the studies analysed by Jónsson and Davíðsdóttir (2016) is given in Figure 7.6. For each soil ecosystem service they provide information about the valuation methods used and the range of values found in the different studies.

Soil service category	Services/functions	Valuation method	International dollar (id$) 2012	id$ units
Support functions	Biodiversity pool	Various methods	2.1 trillion	$\text{id\$/yr}^{-1}$
	Nutrient cycling	Replacement cost, market price, hedonic price	24–180	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Soil formation	Market price	18–28	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Water cycling	Market price	62–126	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
Regulating services	Biological control of pests and diseases	Avoided cost, provision cost	59–268	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Climate regulation	Choice experiments, market price, replacement cost	2–268	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Hydrological control	Damage cost, hedonic cost, replacement cost, benefit transfer, defensive expenditure, provision cost, contingent valuation, choice modelling	30–1175	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Recycling of wastes and detoxification	Provision cost	77–330	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Filtering of nutrients and contaminants	Provision cost, defensive expenditure	544–6402	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
Provisioning services	Biomass production	Market price, producers price	231–22,219	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
	Clean water provision	Damage cost, net factor, hedonic cost	34–101	id$/ML
	Raw materials	Producers price	9–147	id$/t
	Physical environment	Defensive cost, replacement cost, provision cost	32–110	$\text{id\$/ha}^{-1}/\text{yr}^{-1}$
Cultural services	Heritage	Net factor	ND	No data
	Recreation	Damage cost	571,720	$\text{id\$/yr}^{-1}$
	Cognitive	No data	ND	No data

Figure 7.6: Summary of monetary values from soil valuation studies analysed by Jónsson and Davíðsdóttir (2016)

Overall, it can be said that while there exist a number of studies looking at soil ecosystem services, most of them focus on a handful of easily valuable ecosystem services (particularly carbon storage and nutrient retention) and a handful of valuation methods, mainly cost-based methods.

Also, there exist relatively many studies looking at the economic costs of soil erosion (Adhikari and Nadella, 2011; Görlach et al., 2004; Robinson et al., 2014; Table 7.2). Often these studies used restoration costs or similar cost-based methods to establish the economic value of the prevention of soil erosion. Soil erosion leads to the loss of a large variety of ESS (Baveye et al., 2016). Many of these ESS are public goods. Thus, cost-based methods can be expected to seriously underestimate the social costs. Accordingly, Almansa et al. (2012) compared the 'traditional' restoration cost approach with a survey-based economic technique for the valuation of non-market resources. They found that the values generated were around twice as high as restoration costs. Another study in which preference-based valuation approaches were used to analyse the social costs of soil erosion found significant willingness-to-pay for the prevention of off-site effects of soil erosion: landscape desertification, surface and groundwater quality, quality of flora and fauna (Colombo et al., 2005, 2003). Many of these studies do not disentangle the different ESS and benefit / lost and offer a rather crude proxy of soil ecosystem services.

Table 7.2: Estimates of annual costs of soil erosion in Europe (EUR/ha) (EEA 2016a, Görlach et al 2004.)

	On-site costs		Off site costs		total
	Production losses / damage	Mitigation costs	Damage costs*	Mitigation	
Upper estimate	11	29	169	26	235
Central estimate	8	3	86	26	122
Lower estimate	0.50	0	21	0	22

* Includes damage to surface waters (loss of fisheries, siltation, nutrient enrichement etc) from sediment transfer

8 Contributions from research projects and case studies

There is an increasing interest in the concept of soil ecosystem services which is reflected in recently completed and ongoing research projects. This chapter provides information on how particular projects can contribute to knowledge on the role of soil ecosystem services and valuation. Note that the overview is not exhaustive. For all described projects, a factsheet with more information is provided in Appendix II.

8.1 Overview of research projects and case studies

INSPIRATION - Integrated Spatial Planning, Land Use and Soil Management Research Action (2015-2018; EU level - 17 countries involved)

Short project description

INSPIRATION has developed a Strategic Research Agenda (SRA) for Europe on soil, land use and land management. INSPIRATION adopted a bottom-up approach, where national key stakeholders coming from funders (public and private), knowledge producers, end users of research and NGO's in the participating INSPIRATION countries were highly involved. The INSPIRATION goals were: Collate national research demands based on key stakeholder interviews, workshops and desk-work; Establish critical knowledge gaps between the societal challenges for sustainable land-use and the current knowledge on land management and net impact of land-use; Synthesize current state of research demands; Formulate, consult on and revise a strategic research agenda (SRA) to fill uncovered gaps; Scope out models for funding and implementing the SRA; Convene and consult with groups of policy makers, research funders, end users and knowledge creators/ disseminators from both within the EU and beyond.

Contribution to ESS assessments

Many topics proposed for the SRA refer to soil ecosystem services and identify the practical knowledge needs. The topics cover all terrestrial ecosystems (forest, agricultural, urban) and freshwater ecosystems. The project defines research needs in the area of ESS, e.g. balancing the demand for and supply of resources and natural capital and reducing the ecological footprint by proper land management methods and tools. The ESS concept has been a key element in this endeavour. Many knowledge gaps still exist, among others on mapping and assessment of soil ecosystem services.

RECARE - Preventing and remediating degradation of soils in Europe through land care (2014-2018; EU level - 15 countries involved)

Short project description

The main aim of RECARE is 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 pressures in different bio-physical and socio-economic environments across Europe. The research involves: assessing the current state of degradation and conservation using innovative procedures; quantification of impacts of degradation and conservation on soil functions and ecosystem services in a harmonized, spatially explicit methodology; selection, implementation and evaluation of prevention, remediation and restoration measures in a participatory process; assessing the applicability and impact of these measures at the European level using an integrated bio-physical and socio-economic model impacted by economic development and policies.

Contribution to ESS assessments
Different prevention, remediation and restoration measures are likely to have various effects on soil functioning and wider ecosystem services provisioning. These effects are captured by key soil properties and by impact indicators, ranging from bio-physical indicators such as reduced soil loss or increased soil organic matter, to socio-economic indicators such as increased production or reduced workload. Many of these can be quantified, but others need to be estimated or assessed through proxy indicators (which indirectly assess an impact, such as reduced need for fertilizer representing soil fertility increase) in order to get a comprehensive appraisal of the prevention/remediation impact on the various soil functions. Some proxy indicators will be identified through contingent valuation, which considers the socio-environmental returns of different options (i.e. evaluates stakeholders' willingness to pay for e.g. water quality or biodiversity). The aim is to identify and quantify missing indicators and finally combine them into meaningful aggregate indicators, which enable a quantification of the ecosystem services provided by, and enhanced through, the remediation measures, both at the field trial and the entire Case Study level.

LANDMARK - Land Management: Assessment, Research Knowledge Base (2015-2019; EU level - 22 countries involved)
Short project description
LANDMARK combines academic and applied research institutes, chambers of agriculture and policy makers for developing a coherent framework for soil management aimed at sustainable food production across Europe. The LANDMARK project provides the concept that soils are a finite resource that provides a range of ESS known as "soil functions". The project focuses on 3 different levels of impact: local (developing a toolkit for farmers with cost-effective, practical measures for sustainable soil management); regional (soil monitoring scheme, using harmonised indicators for the assessment of soil functions for different soil types and land-uses for all major EU climatic zones); EU scale (assessing EU policy instruments for incentivising sustainable land management).

Contribution to ESS assessments
The project refers to functions relating to agriculture: 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. Therefore the project develops a coherent scientific and practical framework for the sustainable management of soils. The project provides the following outputs:

- Models for 5 soil functions (DEXi qualitative decision models; data mining regression model; bayesian belief model to develop demand and supply maps; diagnostic features model);
- Methodology/model (logical sieve plus soil functions response curves);
- Tools at local scale (soil navigator);
- Maps of each function.

Renewing the impact assessment of land consolidation: the contribution of ecosystem services (2015-2016; regional level - Wallonia, Belgium)
Short project description
The project aims at developing a methodology for impact assessments of land-consolidation plans based on ESS. The methodology is directly applied on the land-consolidation plan of three municipalities in Wallonia (Fernelmont, Eghezée and Wasseiges). After predefining a list of locally relevant ESS and a typology of ecosystems, biophysical and social valuations are carried out.

Contribution to ESS assessments

The project uses the interesting concept of ESS valuation combining data management and a participatory approach. The social valuation comprises two steps: ranking of the most important ESS assessed by focus groups of stakeholders, the Delphi and "management by consent" methods; and participatory mapping of the perception of the supply and of the demand of these most important ESS, with a specific focus on cultural ESS. The biophysical valuation includes mapping and quantification of ESS based on indicators obtained from a hydrological model, and scenario development of potential ESS supply. Participatory comparison of ESS supply and demand then guides land-consolidation actions. Following the development and testing the methodology, operational tools were produced and ESS-based methodology to assess impacts of land consolidation plans were transferred to end users.

Land consumption in Italy

Short project description

In the project ESS and their link with agricultural and natural soil loss due to artificial land cover development were analysed and mapped. The assessment was achieved from both biophysical and economic point of view, using, only for five, InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs; AA.VV., 2015) models.

Contribution to ESS assessments

Nine ESS (Carbon Storage and Sequestration, Habitat Quality, Crop Production, Timber Production, Water Purification, Erosion Protection, Pollination, Microclimate Regulation, Particulate and Ozone Removal) were analysed and mapped. Also a link with agricultural and natural soil loss due to artificial land cover development was made.

LIFE SAM4CP - Soil Administration Model For Community Profit (2014-2018; local level – Italy)

Short project description

The project aims at developing an easy-to-use tool (simulator) for decision makers, enabling assessment of the environmental and economic costs and benefits associated with urban planning and land use scenarios. It is assumed that the tool will help to avoid land-use change decisions that disproportionately reduce soil functions.

Contribution to ESS assessments

The developed tool uses 7 main ecological functions provided by soil in order to map and integrate them, and their potential gain or loss, into the decision-making process. The functions are: carbon sequestration, habitat quality (biodiversity), water purification and retention, soil erosion, wood production, pollination, agricultural production. The project demonstrates how to implement the use of an indicator-based tool and integration of soil protection considerations into the decision-making process in order to protect enhance the ecological functions for the benefit of the local community.

LUCAS - Land Use/Cover Area frame statistical Survey (2009 – ongoing; EU level)

Short project description

LUCAS is an EU-wide soil monitoring 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. It covers all EU countries and recently Croatia, Albania, Bosnia-Herzegovina, Republic of Macedonia, Montenegro, Serbia and Switzerland. Currently it involves approximately 260,000 permanent monitoring locations. Since the first edition, topsoil samples have been collected and analysed for the range of properties describing soil quality and multispectral properties. In the subsequent editions, soil contamination with trace elements (2012) and soil erosion, the thickness of the organic horizon, soil bulk density and soil biodiversity (2018) were included. Soil information can be correlated to land cover (crop) and land use type described in the sampling location. Soil information from 2009 has been released to the public, whereas analyses of samples collected during 2015 are ongoing and data will be available at the middle of 2018.

Contribution to ESS assessments

As the first European-wide soil monitoring programme it can strongly contribute to mapping of soil condition and soil ecosystem services at European level. Soil parameters such as soil organic carbon, pH or soil texture are important for modelling or evaluating provisioning (food and fibre production) and regulating (e.g. water purification) soil ecosystem services. Soil organic carbon content and the recently included thickness of the organic horizon in organic-rich soil can be used to monitor trends in carbon sequestration and climate regulation services whereas soil biodiversity indices measured in LUCAS will help to evaluate soil habitat function.

TEEB city tool - Further development of the urban planning support tool 'TEEB city tool', on valuation of natural capital and ecosystem services (green and water) in cities (2016-2018, national level – The Netherlands)

Short project description

The project is aimed at further development and use of the so-called TEEB-city tool which enables integration of health and well-being, climate change adaptation, water management and biodiversity issues into the urban planning process. The project involves seven Dutch cities and their collaboration with knowledge institutions, consultancies, gardeners association and citizen groups. Strong stakeholder participation is assumed in co-creation of urban plans in order to increase the sustainability and effectiveness of nature-based interventions.

Contribution to ESS assessments

The TEEB tool is freely accessible to planners, city authorities, developers, companies and citizen groups. They can use it to calculate and understand the value of green and blue infrastructures in their neighbourhoods. There is potential for further development of the tool as dynamic 3D knowledge platform.

URBAN SMS – Urban Soil Management Strategy (2008-2012; Central Europe)

Short project description

The project was aimed at exchange of experiences in soil management under urbanization pressure. The guidelines for better inclusion of soil protection into spatial planning and environmental impact assessment procedures were developed. Computer tools were developed and tested in pilot cities to support spatial planning process that takes soil issues into consideration. Spatial analysis of urban sprawl and analysis of soil policy effectiveness in several cities of Central Europe were performed.

<u>Contribution to ESS assessments</u>
The participatory impact assessment was adjusted and applied for assessing urbanization consequences for soil functions in three dimensions of sustainable development (social, economic, environmental). The local stakeholders were led through steps of the impact assessment in order to ascertain and quantify their opinions on importance of soil functions and effect of soil protection scenarios on these functions. The workshops were organized in six cities of Central Europe. The baseline scenario assuming that nothing would change in regulations concerning soil protection, and therefore trends in land take would be constant, was assessed as favourable to economic functions. Opposingly, all environmental functions (retention, providing biodiversity and filtering) were deemed as highly threatened under the baseline scenario.

ENVASSO - Environmental Assessment of Soil for Monitoring (2005-2008)
<u>Short project description</u>
ENVASSO was aimed at defining a monitoring system and its potential implementation and developing a framework for European soil monitoring. Indicators were selected to monitor various 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. Due to the lack of adequate indicators, new methods for monitoring wind erosion, tillage erosion and carbon stocks in peat soils were formulated. A tiered approach for the implementation of soil monitoring is 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, when intensive sampling was needed to describe soil processes or when proficiency exercises to assess variability associated to different field teams were performed.

<u>Contribution to ESS assessments</u>
The project proposed realistic indicators for the range of threats to soil, to be used in monitoring soils at European scale. Many of these indicators are useful for characterizing soil ecosystem services. E.g. indicators for soil compaction can address water flow service, soil organic carbon can address impact on climate, soil biodiversity indices characterize soil as a habitat.

Table 8.1. Types of ecosystem and pressures addressed by the research and implementation projects

Project title	Type of terrestrial ecosystems	Addressed pressures	How project improves potential/capacity for soil related ESS
INSPIRATION	Forest, agricultural, urban	Wide range of pressures	Defining research needs within ESS combined into Strategic Research Agenda for Europe
RECARE	Forest, agricultural, urban	Erosion, salinisation, compaction, sealing, desertification, flooding and landslides, loss of SOM, contamination, loss of biodiversity	Identification of indicators and methodology for ESS assessment. Evaluation of soil protection or remediation practices on ESS

Project title	Type of terrestrial ecosystems	Addressed pressures	How project improves potential/capacity for soil related ESS
LANDMARK	Forest, agricultural	Wide range of pressures, however focused more on soil functions than threats to soil	Models and tools for ESS assessment, mapping of ESS
Renewing the impact assessment of land consolidation: the contribution of ESS	Agricultural	Unfavourable land fragmentation	Methodology to incorporate ESS into land consolidation practices
Land consumption in Italy	Agricultural, forest, urban	Sealing	Mapping and analysis effects of artificial land cover on ESS
LIFE SAM4CP	Forest, agricultural, urban	Land use and habitat change	Tool for incorporation of ESS into urban planning
LUCAS	Forest, agricultural	Soil contamination, soil erosion, compaction, (loss of) soil organic matter and soil biodiversity	Soil monitoring for assessment of soil condition and soil parameters affecting soil ESS
TEEB city tool	Urban	Climate change, habitat change, decrease in biodiversity	Tool for incorporation of ESS into urban planning
URBAN SMS	Urban	Sealing	Methodology for assessing scenario impact on land/soil functions
ENVASSO	Agricultural, urban	Erosion, organic matter decline, contamination, compaction, salinisation, decline in biodiversity, soil sealing, landslides and desertification	Soil monitoring, indicators for soil threats and characterizing soil ESS

8.2 Conclusions on contribution of research projects and case studies

Ecosystem service assessments receive an increasing attention in ongoing soil related research and implementation projects. Some projects develop a concept of soil protection based on ESS assessment. The methodological transition from a land functions concept to ESS is also observed. Substantial effort is made to develop methodologies of EES valuation and indicators of particular ESS for which a combination of data transformation and participatory approach is often used.

It is also clear that to make the ESS approach fully interoperable and applicable, ESS have to be translated into spatial format and mapped. In general, international projects provide general concepts for assessment of soil ESS that are subsequently adapted to local or national circumstances. Local projects, characterized by a strong influence of stakeholders, especially in urban environment, are more focused on “ready to use” tools to be applied for improved spatial development.

9 Conclusions and recommendations for next steps

9.1 Results of the MAES integration of soil in ecosystem assessments

The MAES Soil Pilot aims to increase awareness on the importance of soil functions and soil ecosystem services, by showing their value for society and the need to protect, manage and restore this value. In this context the JRC developed a diagram for the Soil Pilot to demonstrate how ESS rely on soil condition, which in turn is influenced by soil pressures (Figure 9.1). This chapter provides a synthesis of the available information on soil ecosystem services.

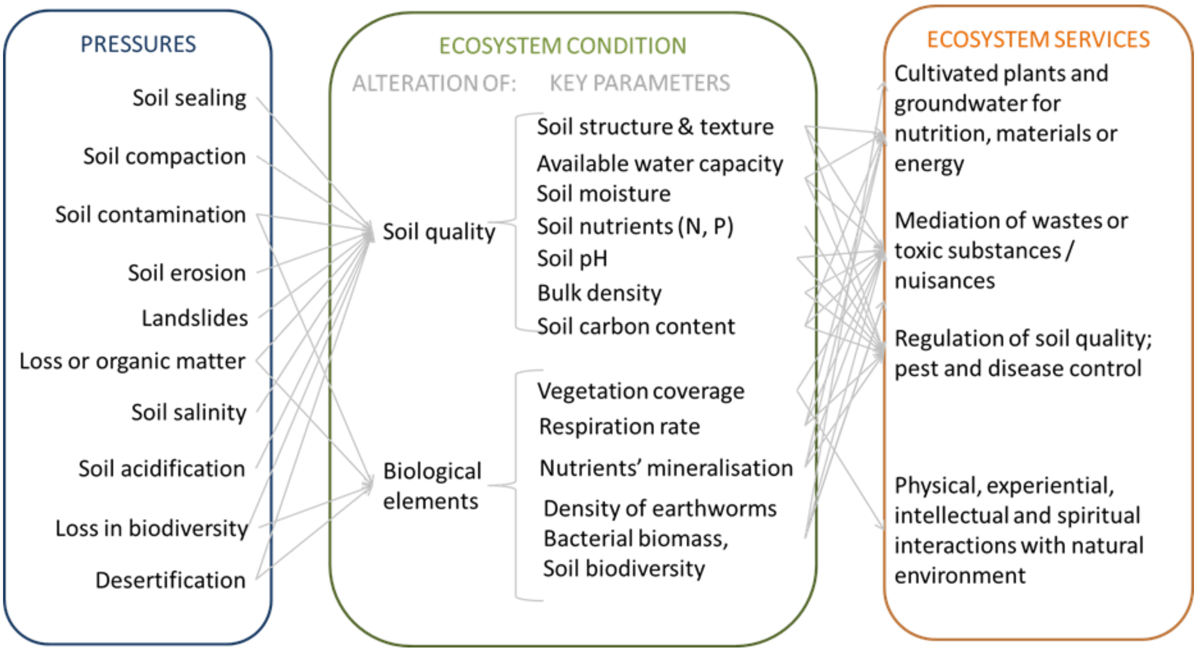

Figure 9.1: This figure explains how the delivery of soil ecosystem services depends on ecosystem condition, which in turn is influenced by soil pressures (Developed by JRC's MAES Soil working group, 2017)

In section 9.2 we draw conclusions on which ESS can be regarded as soil ESS. Section 9.3 describes the impact of land and soil management practices on ESS through their influence on soil condition. Most recommended practices are targeted at preventing adverse impact on ecosystem services by mitigating soil pressures. Sections 9.4 and 9.5 provide a synthesis of available information on the status of soil ESS in Europe, their value and knowledge gaps.

Based on available knowledge, recommendations are provided in this chapter for two distinct user groups: 1) practitioners who manage soil or influence soil such as policy makers, urban designers and farmers; 2) scientists and research funders in the fields of soil, land management and ecosystem services.

9.2 Which ecosystem services to include in a soil assessment?

This report provides the most comprehensive overview of ESS related to soil, building on publications that each shed light on specific subsets of services. All ESS included in this report (see Table 3.1. for an overview) meet the criteria of ESS theory, being goods or services that are provided by the ecosystem, used by humans, contributing to human well-being and clearly depending on soil. Some of these soil ESS are often not included in general ESS assessments or in soil ESS assessments, due to a lack of data on the appropriate scale.

In most publications about soil ESS, the production of food crops, wood and fibre is mentioned. This is obvious since soils play a major role as substrate for crops and trees (even though crop production depends on other factors as well). According to the same logic, in urban areas soils are important for human well-being because they provide substrate for vegetation that contributes to human health by improving thermal comfort, air quality or recreation potential. For this reason, air quality regulation and regulation of local climate are included in our list of soil ESS. Besides this rather indirect influence, there is also a direct link between air quality and soil, e.g. through dust from soil. Similarly, noise abatement is influenced indirectly (via vegetation) and directly by soil properties. Following the logic of soil as substrate for vegetation, prevention of soil erosion by vegetation could be considered. However, this leads to circular reasoning and therefore erosion control has been excluded. For clarity, it was indicated if a soil ESS is a primary (direct) or secondary (indirect) soil ESS.

For subsurface thermal energy, we distinguish between shallow and deep applications. Thermal energy extraction and storage enables heating and cooling of buildings by using the temperature buffer capacity of the soil. Shallow systems are influencing the subsurface ecosystem and depend on its management, especially through impacts on groundwater.

For cultural services, the role of soil is in general poorly elaborated.

Recommendations for practical soil management and policy making:

- Structural analysis by policy makers and soil managers of the impact of their decisions on soil ecosystem services will enable them to make well informed decisions. A good understanding of the role of soil in the provision of ESS and thus for human well-being will enable practitioners to develop soil management practices that have a positive impact on human well-being. Therefore it is advisable to use instruments such as Environmental Impact Assessment and Strategic Environmental Assessment, and to try to integrate the impact on the provision of soil ecosystem services in these evaluations. This approach can help to achieve multiple Sustainable Development Goals.
- When analysing the impact of management practices on ESS, it is recommended to start with a scan that encompasses the whole list of ESS. This will ensure a broad overview and prevent that less obvious aspects are neglected. It is important to also consider the trade-offs between the potential supply, actual use and future demand of multiple ecosystem services: the use of one service may result in reduced capacity of another service. Even when there is a rather indirect impact of changes in soil characteristics on ESS, this impact could be high. For example, temperature regulation by vegetation through transpiration may be severely impaired by a lack of available soil moisture.

Recommendations for future research:

- For consistent use of soil ESS, it would be helpful to further assess the contribution of soil (compared to other environmental compartments) in the provision of ESS. The trade-offs between services as result of land management decisions should be more closely investigated. The role that soil plays in the provision of cultural ESS is still largely unknown territory.

9.3 The impacts of land and soil management practices on ESS

There is no standard recipe for good soil and land management in relation to ESS provision. Since there are many trade-offs between services, the optimal management depends on which ESS are demanded by the stakeholders and the society and on the variability of local soil characteristics. Chapter 6 demonstrates that some practices impact multiple ESS or specific bundles of ESS. For example: reduced tillage on agricultural land can increase carbon sequestration and soil biodiversity (and related soil ESS) and is also influencing water regulation. An evaluation of the potential provision and actual use of ESS should be used to prioritize management actions and to guarantee a sustainable use of the ecosystem and the soil.

Management practices that help the delivery of multiple ESS as described in chapter 6 should be favoured. Decisions are heavily influenced by the demand for ESS and the value that decision makers or society assign to certain services. The current and future needs of humans here and elsewhere determine the sustainable provision of soil ESS.

Recommendations for practical soil management and policy making:

- Consider the potential provision and actual demand of ESS and trade-offs between ESS as integral as possible. By assessing potential supply and use, it is possible to determine whether the use of soil is sustainable. Examples of this type of analysis from Flanders and the Netherlands are provided in chapter 3.4 of this report. These examples demonstrate that many soil ESS are used in an unsustainable way at the moment.
- Analysis of potential supply and demand of ESS should be spatially and temporally specific. See section 3.3 for more information on indicators and datasets that can be used.

9.4 The condition of soil ESS: what we know about potential and use

For provisioning services, production and use, are well documented. Agricultural outputs in Europe increased between 2000 and 2010. At the same time, potential supply of these goods seems to decline based on available arable land and soil fertility. This may indicate unsustainable use of the crop production service, which is supported by studies in Flanders and the Netherlands. Maes et al. (2015b) suggest using surface area of organic crops as proxy indicator for the potential of the ecosystem to provide agricultural crops. Further indicator development and data gathering is recommended.

In terms of water provisioning, extractions decreased between 2000 and 2010. Since no distinction is made between surface water and groundwater, we do not know if this is also true for groundwater. Modelling shows that groundwater stress occurs in the EU due to extraction exceeding the potential. Further assessment of groundwater resources is needed to improve insight in the potential of the subsurface system to provide freshwater and brackish water and to relate this to the demand for water with certain quality.

From the European studies that we considered, it is hard to determine if regulating services for water quality and quantity in relation to soil are improving or declining. One reason is that the role of soil is hidden in indicators that provide insight in water quantity and quality regulation as a result of several processes and structures, where soil is only one part of the equation. Examples of integrative indicators are water retention capacity as used by Maes et al. (2015b) and relative water purification capacity of freshwater ecosystems (Maes et al., 2011) expressed as nitrogen removal. It would require more in-depth investigation to identify the role of soil (e.g. potential removal independent of loading yields) in these indicators.

Nevertheless, integrated indicators are valuable because they stimulate a holistic approach and acknowledge the importance of the entire ecosystem, with all its components and processes, for the provision of ESS. Extracting the role of soil however may be useful for soil scientists and soil managers to develop soil management practices that enable more sustainable use of specific bundles of soil ESS.

Another difficulty with several regulating services is that their use is strongly spatially specific; potential supply and demand need to be located close to each other or even at the same geographical spot. For traffic noise reduction by bare soil and vegetation for example, the physical structure reducing noise should be directly next to a road. The same applies for the provision of shading by trees. This level of spatial detail is lost in assessments and maps at European scale unless they are provided in a very fine resolution.

For some ESS, a combination of indicators can be used as proxy to provide insight in the potential. As indirect indication for regulation of local climate, specifically for the aspect of increasing thermal comfort, the combination of soil sealing and water availability or drought data would give a good indication.

Recommendations for future research:

- In order to improve sustainable land use, the relation between the flows and potential of ESS should be assessed together with the role of soil in the potential supply. This will provide insight in the degree of sustainability of the use of these services.
- New tools for the assessment of ecosystems and trade-offs between their services should be developed and integrated in land-use and land management decisions.
- Although integrated indicators for regulation and maintenance services are valuable because they acknowledge the importance of an entire ecosystem, extracting the role of soil may be useful for soil scientists and soil managers to develop soil management practices that enable sustainable use of specific bundles of soil ESS.
- The potential and use for the provision of regulating services is often spatially specific and very local. The required level of spatial detail is lost in assessments and maps at European scale unless they are provided on a very fine resolution.
- When indicators for ESS potential are lacking, a combination of indirect indicators can provide insight in the potential. The production of new maps in which these indicators are combined would be very useful in the future.

9.5 The economic impact of changes in ESS

The economic valuation of soil ESS, which was discussed in chapter 7, can inform decision-making on soil management at various organisational levels, but is still a nascent area of research. Conceptually, a unified framework does not exist; methodologically, the most common approaches lag behind the developments in general economic valuation research.

There are generally very few studies available, most of which focus on a handful of soil ecosystem services. Particularly, there are very few economic valuation studies of soil ESS conducted in Europe. Of the thirty-three soil ESS valuation studies included in the review by Jónsson and Davíðsdóttir (2016), only five were conducted in Europe. Moreover, they found that virtually all economic valuation studies of soil ecosystem services focus on agricultural contexts.

The available studies use very diverse, qualitatively divergent methods and approaches, which makes their results hardly comparable. The field does not provide many insights into the economic value of soil ESS beyond orders of magnitude. As a matter of consequence, economic valuation studies do not provide much information that can be informative for decision-making processes beyond the available biophysical data.

Recommendations for future research:

- There is significant potential for new research in this area. Much effort in developing soil-specific approaches to economic valuation would be needed.
- Since current research is limited mostly to agricultural contexts and only a limited amount of studies is conducted in Europe, more focus on other contexts (e.g. urban soil ESS) and more research in Europe will improve the availability of information for decision makers in Europe.

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Annex I European and International soil related policy

There is a strong link between the MAES soil pilot and policy. This annex describes and summarizes the most important European and international policies.

European soil related policy

Thematic strategy for soil protection (Soil Thematic Strategy, STS)

The main EU soil policy instrument is the Soil Thematic Strategy (STS)[45] which was adopted in 2006 and aims to protect European soils through the prevention of further degradation, the conservation of soil functions and the restoration of degraded soils. The strategy consists of a Communication from the Commission, a proposal for a Soil Framework Directive and an Impact Assessment.

The Communication assesses the magnitude of soil degradation and explains why further policy action is required at European level. Several key threats to European soil quality are identified: erosion, decline in organic matter, local and diffuse contamination, sealing, compaction, loss of biodiversity, salinisation, floods and landslides. The STS defines the common approach to counter soil degradation in the EU and sets the frame by stating the four key pillars of action around which policy measures have to be taken:

- Integration of soil protection in the formulation and implementation of national and EU policies;
- Closing the recognised knowledge gap in certain areas of soil protection through research supported by EU and national research programmes;
- Increasing public awareness of the need to protect soil;
- Development of framework legislation with protection and sustainable use of soil as its principal aim.

In order to implement this last pillar of action, the STS was accompanied by a proposal for a Soil Framework Directive[46]. The European Parliament adopted a positive opinion on the text in first reading in November 2007. For a number of years very difficult and sensitive political discussions took place in the Council of the EU under the successive EU presidencies which, despite the efforts of many involved, never achieved to reach a common position due to a blocking minority of 5 Member States. Finally, after been pending for eight years, the proposal was withdrawn in May 2014 by the Commission leaving open to the next Commission to decide on a new initiative.

The 7th Environment Action Programme

Environment Action Programmes have guided the development of EU policy since the early seventies. During this period, environment legislation was consolidated and completed to cover almost all environmental media like air and water, with one exception: soil. After the withdrawal of

[45] COM(2006) 231.Communication from the Commission on the Thematic Strategy for Soil Protection

[46] COM(2006) 232. Proposal for a directive of the European Parliament and of the council establishing a framework for the protection of soil and amending. Directive 2004/35/EC. Brussels, 22.9.2006.

the proposal for a Soil Framework Directive[47], the Commission, together with the European Parliament and the Council of the EU, remained fully committed to the protection of European soils. This engagement is reflected in the 7th Environment Action Programme[48] which states that by 2020 "land is managed sustainably in the Union, soil is adequately protected and the remediation of contaminated sites is well underway" and that this requires "increasing efforts to reduce soil erosion and increase soil organic matter, to remediate contaminated sites and to enhance the integration of land use aspects into coordinated decision-making involving all relevant levels of government, supported by the adoption of targets on soil and on land as a resource, and land planning objectives".

The Commission decided to set up an expert group with the mandate based on the 7th EAP commitment that "*the Union and its Member States should also reflect as soon as possible on how soil quality issues could be addressed using a targeted and proportionate risk-based approach within a binding legal framework*". The experts were nominated by the Member States and have the required connection with national authorities dealing with soil issues at a political level. The expert group met for the first time in October 2015 and continues to do so twice a year.

Integration of soil protection in other EU policies

Given the cross-sectorial nature of soil issues, the diversity of environmental and socio-economic pressures and governance conditions across Europe, it is not surprising that many different policy instruments at EU and Member State level exist and offer some form of protection for soils. The STS envisages to further integrate soil protection in other policy areas, inter alia: agriculture, regional development, transport and research.

The European Commission launched a study published in February 2017 (Frelih-Larsen et al., 2016) which provides an updated inventory of more than 700 policies and measures at EU and national level with relevance to soil and identifies the key gaps in protection with respect to soil pressures and functions, identified following policies and measures at EU level with relevance to soil.

Strategic initiatives	
7th Environment Action Programme	Resource Efficiency Road Map
EU Forest Strategy	Circular Economy Action Plan
Adaptation Strategy	Biodiversity Strategy
Soil Sealing Guidelines	Soil Thematic Strategy

[47] COM(2006) 232. Proposal for a directive of the European Parliament and of the council establishing a framework for the protection of soil and amending. Directive 2004/35/EC. Brussels, 22.9.2006.
[48] Decision No. 1386/2013/EU of the European Parliament and of the Council on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'

Binding Measures – Directives, Regulations, Decisions	
Effort Sharing Decision	Sewage Sludge Directive
Environmental Impact Assessment Directive	Strategic Environmental Assessment Directive
Environmental Liability Directive	Waste Framework Directive
Fertiliser Regulation	Drinking Water Directive
Floods Directive	National Emission Ceiling Directive
Groundwater Directive	Water Framework Directive
Habitats and Birds Directives	Cohesion Fund
Industrial Emissions Directive	Common Agricultural Policy
Landfill Directive	European Regional Development Fund
LULUCF Decision	European Social Fund
Mercury Regulation	LIFE Programme
Nitrates Directive	State Aid Guidelines
Pesticides Directive	Horizon 2020
Renewable Energy Directive	

The same study concluded that some relatively strong EU policies are in place that help mitigate, manage and prevent soil degradation processes (e.g. the Environmental Liability Directive[49], Industrial Emissions Directive[50], the 7th EAP[51], the Common Agricultural Policy, funding instruments, etc.). However it also identified major gaps in particular on historical soil contamination (which is not addressed by the Industrial Emission Directive or the Environmental Liability Directive) as well as the absence of standards on soil contaminants at EU level. The protection of agricultural soil is addressed in the Common Agricultural Policy but a lot of flexibility is left to the member states in the implementation and the measures are insufficient to promote soil sustainable management in a comprehensive way. On the contrary unsustainable soil management practices are still commonly used in conventional agriculture, with transboundary impacts. There are also no common definitions for good soil ecosystem condition, no common targets and priorities, no harmonised soil monitoring parameters and no definition of the role that the different policy instruments should play in delivering good soil ecosystem condition.

[49] Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage
[50] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)
[51] Decision No. 1386/2013/EU of the European Parliament and of the Council on a General Union Environment Action Programme to 2020 ‘Living well, within the limits of our planet’

In absence of EU soil legislation, soil protection on EU level is mostly an outcome derived from the protection of other environmental resources and from addressing other environmental threats or targets. The need to promote more holistic soil management asks for a coherent strategic policy framework and a political or legislative driver at EU level.

European Inventory and Assessment of Soil Protection Policy Instruments

The (updated) European Inventory and Assessment of Soil Protection Policy Instruments in the EU Member States is a virtual repository in which individual MS provide information on national soil –related policies. Next to that, key gaps in protection with respect to soil threats and functions from the Thematic Soil Strategy were identified.

Developing an improved understanding of existing policy instruments and gaps in soil protection, contributes to developing a baseline on which to build further policy action on soils in the EU, intended as a basis for discussion around the role of policy for soil protection in Europe (Frelih-Larsen et al., 2017) .

Integration of soil protection in other international policies

At international level there is growing awareness on land and soil degradation and the need to preserve and restore these essential natural resources. This evolution is reflected in the agenda of several international conventions and United Nations agencies, and is expected to have a big impact on the soil policy of the European Union and its Member States.

International soil related policies and initiatives	
2030 Agenda for Sustainable Development (2030 ASD) and sustainable development goals	United Nations Environment Programme (UN Environment, UNEP)
United Nations Convention to Combat Desertification (UNCCD)	Convention on Biological Diversity (Biodiversity Convention, CBD)
United Nations Framework Convention on Climate Change (UNFCCC)	Global Soil Partnership (GSP)

2030 Agenda for Sustainable Development (2030 ASD) and the United Nation's Sustainable Development Goals

A part of the 2030 Agenda for Sustainable Development, world leaders adopted 17 Sustainable Development Goals (SDGs); they officially came into force in 2016. The SDG's call for action by all countries in the world, with the aim to promote prosperity while protecting the planet. SDGs are not legally binding. The role of soil in the Sustainable Development goals is further elaborated underneath.

Soil related ecosystem services, like all ESS, contribute to human well-being. For example, health benefits are provided through *provision of food* and the regulating service *water purification and soil contaminant reduction.* Another benefit is safety provided by mitigation of floods through the *water regulation* service.

In the description of several SDG's, the words *soil, land, water, natural resources* and *ecosystems* are mentioned in explicitly (literal citations). The sub-goals that include these words are listed below.

SDG 1. End poverty in all its forms everywhere

- By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.

SDG 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

- SDG 2.3: By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment .
- SDG 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.

SDG 3. Ensure healthy lives and promote well-being for all at all ages

- SDG 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
- SDG 3.c: Substantially increase health financing and the recruitment, development, training and retention of the health workforce in developing countries, especially in least developed countries and small island developing States
- SDG 3.d: Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks

SDG 6. Ensure availability and sustainable management of water and sanitation for all

- SDG 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all
- SDG 6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
- SDG 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
- SDG 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
- SDG 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
- SDG 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
- SDG 6.a: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
- SDG 6.b: Support and strengthen the participation of local communities in improving water and sanitation management

SDG 7. Ensure access to affordable, reliable, sustainable and modern energy for all

- SDG 7b: By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support

SDG 11. Make cities and human settlements inclusive, safe, resilient and sustainable

- **SDG 11.5:** By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
- **SDG 11.b**: By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels

SDG 12. Ensure sustainable consumption and production patterns

- SDG 12.4: By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment

SDG 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

- SDG 14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

- SDG 15.1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
- SDG 15.2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally
- SDG 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world
- SDG 15.8: By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species

Lobos Alva et al. (2015) have proposed soil indicators to monitor the achievement of the Sustainable Development Goals (SDGs). One of the indicators is *carbon sequestration* [soil organic carbon storage] to monitor the soils' contribution to amongst others, SDG 13: 'Take urgent action to combat climate change and its impacts'. Another example is 'land productivity' which is linked to the ecosystem services *provision of food, wood and fiber* and which is proposed as indicator for several SDG's such as SDG2: 'End hunger, achieve food security and improved nutrition, and promote sustainable agriculture'.

United Nations Environment Programme (UN Environment, UNEP)

UNEP is the global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system and serves as an authoritative advocate for the global environment see www.unep.org). It contributes to the development of international conventions, implements and funds environmental projects, promotes the science-policy interface and supports countries with the implementation of environmental policy. The third session UN Environmental Assembly (UNEA), will be fully dedicated to pollution, soil contamination included.

United Nations Convention to Combat Desertification (UNCCD)

Since its adoption in 1994 and entry into force in 1996, the UNCCD combats desertification and mitigates the effects of drought in countries experiencing desertification, particularly in Africa, through international cooperation and partnership arrangements. All 196 Parties have obligations in terms of the collection of information, research, capacity building and the financial support of countries affected by desertification. These affected Parties have to develop and carry out national, sub-regional and regional action programmes in close cooperation with the local stakeholders. Several Member States are declared as affected parties. The UNCCD is very active on the concrete development and the implementation of the land degradation-neutrality (LDN) principle enshrined in the SDG target 15.3. The LDN objective is to compensate losses with gains, and to achieve a position of no net loss of healthy and productive land.

Convention on Biological Diversity (Biodiversity Convention, CBD)

The Earth's biological resources are vital to our economic and social development but human activities are taking a toll on many animal and plant species. After its adoption in 1992 and entry into force in 1996, the Convention on Biological Diversity pursued the global protection of biodiversity and the sustainable use of biological resources, and also addressed soil biodiversity. The Conference of the Parties decided *"to establish an International Initiative for the Conservation and Sustainable Use of Soil Biodiversity as a cross-cutting initiative within the programme of work on agricultural biodiversity, and invited the Food and Agriculture Organization of the United Nations, and other relevant organizations, to facilitate and coordinate this initiative".* This cross-cutting initiative aims to increase the recognition of the essential services provided by soil biodiversity across all production systems and its relation to land management, to share information, and to increase public awareness, education and capacity-building. In Cancun the ministers and other heads of delegations of the Conference of the Parties of the UN Biodiversity convention declared: "*We are most concerned by the negative impacts on biodiversity caused by degradation and fragmentation of ecosystems, unsustainable land use changes, overexploitation of natural resources, illegal harvesting and trade of species, introduction of invasive alien species, pollution of air, soil, inland waters and oceans, climate change and desertification*"(Cancun declaration, 2016).

United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC was adopted in 1992 and aims to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. Today there are 197 parties to the Convention as it is probably the best known international environmental treaty. The text itself doesn't impose binding targets to the Parties, but it contains the basic framework for climate agreements like the Kyoto protocol or the Paris Agreement. In the context of UNFCCC soil carbon sequestration is recognised as an important way to mitigate and adapt to climate change. At the 2015 United Nations Climate Change Conference in Paris, an initiative was launched by the French government to increase the global soil carbon stock with 4 ‰ annually, in order to stop the increasing CO_2 accumulation in the atmosphere.

Global Soil Partnership (GSP)

The Global Soil Partnership (GSP) has been established, following intensive preparatory work of the United Nations Food and Agriculture Organization (FAO) in collaboration with the European Commission, as a voluntary partnership coordinated by the FAO in September 2011. The GSP is open to all interested stakeholders: governments (FAO Member States), universities, research organizations, civil society organizations, industry and private companies. It is a voluntary partnership aiming to provide a platform for active engagement in sustainable soil management and soil protection at all scales: local, national, regional and global (Montanarella, 2015).

For the implementation, the GSP relies on the Regional Soil Partnerships, the European Soil Partnership being one of them. Meantime, the GSP, together with its regional partnerships and the Intergovernmental Technical Panel on Soil (ITPS) is well recognized for its actions and expertise on soil at global level with the adoption of a revised World Soil Charter, the publication of the Status of the World's Soil Resources report and the Voluntary Guidelines on Sustainable Soil Management. The GSP is currently also developing a Global Soil Organic Carbon map based on national data inputs, in order to highlight the importance of the sequestration of carbon for the climate system, agriculture, human health, agriculture, etc.

Annex II Towards societal benefits by soil services; Background paper, Soil Stakeholders' Conference, 5th December 2016

Towards societal benefits by soil services

Background paper, Soil Stakeholders' Conference, 5th December 2016

Drafted by Margot de Cleen and Co Molenaar (Ministry of Infrastructure and the Environment, Rijkswaterstaat, WVL/Soil plus), Josiane Masson (European Commission, DG ENV) and other members of the MAES Soil pilot group

Introduction

The services provided by soils are vital for Europeans! The EU strategy Europe 2020[1] addresses several societal challenges which the EU wants to achieve smartly, competitively, sustainably and inclusively. Many of these challenges can only be met by sufficient good land and soil availability. However, land and soil availability is under pressure as it is needed for a range of uses such as supporting houses, food and biomass production, biodiversity, water management, leisure and other cultural aspects.

Society at large is not sufficiently aware of the importance and relevance of soil services for meeting societal challenges, such as food security, climate change adaptation and mitigation, energy transition and safe and clean drinking water. Often this leads to significant damage and loss of economic and societal benefits. The risks and costs from an ongoing degradation of ecosystems and their services are neither properly integrated into our economic and social systems nor our decision-making processes (European Environment Agency, 2015[2]). In this context, related knowledge instruments, such as ecosystem accounting, need to be developed. To address societal challenges the multiple-use of land, soil and its services is needed. This needs to be done in a sustainable way to secure these benefits for present and future generations.

Because land is often owned by private parties and used by different stakeholders, solving societal challenges asks for cooperation between public and private parties. For societal benefits, agreements should be made to use this land in such a way that not only the landowners' needs are met, but also societal expectations can be fulfilled. Due to the different interests on how land shall be used, an integrated approach is desired. Therefore, the challenge for policy makers is to develop instruments to better balance private and societal interests. A transition is needed from protection against soil threats towards a sustainable use and a land management in which various stakeholders do participate.

Aim

Action 5 of the EU Biodiversity Strategy to 2020[3] calls Member States to Map and Assess the state of Ecosystems and their Services (MAES) in their national territory with the assistance of the European Commission. MAES addressed a special Pilot on Soil.

With this policy brief the MAES Soil group wants

- To clarify the concept of soil services and its added value for society
- Explore the links between soil services and big societal challenges and instruments;
- Increase the awareness of the importance of well-functioning soil services for EU and Member States challenges by a joint narrative;

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1 EU 2020 a strategy for smart, sustainable and inclusive growth COM(2010)2020

2 "The European Environment State and Outlook 2015, section 3 – protecting, conserving and enhancing natural capital", EEA http://www.eea.europa.eu/soer-2015/synthesis/report/3-naturalcapital

3 COM(2011)244

- Start a transition process towards a more integrated and inclusive approach: soil-sediment-water, soil-plant-water, soil-climate, soil-energy, by moving from soil protection towards soil as a "partner" for meeting societal challenges by sustainable soil use and management;
- Connect stakeholders so they can optimize and share revenues by joint sustainable soil and land management.

Policy Context

The EU and Member States (MS) face several societal challenges, partly driven by global and autonomous developments, such as a growing world and middle class population, climate change and urbanization. It results in increased pressure on land, mineral and natural resources and an increase in protein intake. The United Nations Decade on Biodiversity and the UN Sustainability goals, as well as the Paris COP 21, set goals to cope with these challenges worldwide. The Food and Agricultural Organization of the United Nations (FAO) and the Global Soil Partnership (GSP) show that healthy soils are needed for healthy living. Strategies are needed to achieve transitions in healthy urban living, sustainable food production and resource and energy efficiency. Instruments are sought to sustain these transitions and to help closing cycles and maintain natural capital and biodiversity.

The EU policy goals cannot be achieved without the sustainable use of the soil system. The societal challenges as described in Europe Strategy 2020, all use soil services. The Urban Agenda track green growth also relies on the "sustainable use of land and nature based solutions"[4]. The aim for a circular economy and the roadmap towards a resource efficient Europe includes soil services. The Bio-economy Strategy[5] strongly depends on healthy soils to meet the food and biomass demand in Europe. It may be clear that soil services are a cross-sectoral theme throughout a great part of EU policy. Yet, this fact is not part of the mindset. Therefore, a transition in mindset and policy is needed. Current policies, such as the Voluntary Guidelines for Sustainable Soil Management (agreed upon in the GSP), the Natural Capital Protocol and the Common Agriculture Policy instruments, can be adapted and extended towards sustainable use but also new instruments are needed.

The soil services concept

Soil has several functions which are beneficial to human wellbeing. These functions are related to geological and biological characteristics of the soil-system. Consequently, the use of these functions can be defined as geo system services and soil ecosystem services.[6]

Although the expression "ecosystem services" is of long-standing, there is still misunderstanding about its definition and relation to other concepts, such as soil services, natural system, soil-sediment-water system, natural capital, land use, land management, top layer, subsurface, etc. The MAES project concentrates on ecosystem services. In this paper all system services of soil are addressed. After all, all soil services are relevant for meeting the societal needs.

Some Definitions first

Land is defined as the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological hydrological processes that operate within the system[7]. **Soil** can be defined as the top layer of the Earth's crust. It is formed by mineral particles, organic matter, water, air and living organisms[8].

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4 See: http://urbanagendaforthe.eu/pactofamsterdam/twelve-themes/
5 COM(2012)60
6 The concept of ecosystem services was brought into widespread use by the Millennium Ecosystem Assessment (MA), a global initiative set up in 1999 to assess how ecosystem change would affect human well-being (MA, 2005). The MA defines ecosystem services simply as: "the benefits that people obtain from ecosystems". (See "Science for environment policy in-depth report 'Ecosystem services and biodiversity', May 2015")
7 Article 1 of the UNCCD
8 See: http://ec .europa.eu/environment/soil/index

Natural capital is a stock of natural resources, such as land, water, and minerals, used for production. Can be either renewable or nonrenewable[9].
Ecosystem services are the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfill the needs and wants for human life. Nature includes both living nature and abiotic elements. However, abiotic products and services are excluded from the definition of ecosystem services (EEA,2011)[10].
Geodiversity has been defined as 'the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, processes) and soil features' (Gray 2004, p. 8) and is therefore the abiotic equivalent of biodiversity.[11] Consequently, the rather novel concept of **geosystem services** can be recognized as the goods and functions associated with geodiversity (Gray 2008)[12].
Soil services are the geological and biological services. It is clear that the geosystem and the soil ecosystem are connected in a complex system. For example, groundwater is stored in the geosystem. The quality of the groundwater is secured by the ecosystem. Together these systems secure our drinking water supply.

The soil services can be divided into four categories: provisioning services, regulating and maintaining services, cultural services and supporting services. The quality and availability of the services is determined by local circumstances. (see Figure 1) The value of these services for society can be expressed as natural capital.

Soil ecosystem services			Geosystem services	
Provisioning services	Regulating and maintenance services	Cultural services	Supporting services	Provisioning services
production of crops	clean and safe soil	archeological value	foundation of buildings	stock minerals
stock drinking water	soil biodiversity	geological value	Under-ground infrastruc-ture and construc-tions	stock fossil fuels
stock groundwater	soil stability	landscape diversity	cables, conduits and sewers	Geothermal energy
	water storage capacity	ecological diversity	transport ducts	
	water filtrating and purifying soil		heat-cold storage	
	soil as carbon sink		storage of substances	

Figure 1 - Division of soil services[13]

MAES Soil Pilot

The EU has an implementation program for the UN Decade on Biodiversity[14]. Mapping and Assessment of Ecosystem Services (MAES)[15], natural capital accounting (TEEB[16]) and the natural

9 World Bank Glossary
10 EEA, 2011. Europe's Environment. An Assessment of Assessments. European Environment Agency, Copenhagen http://dx.doi.org/10.2800/78360
11 The term was first used in 1993 (Sharples 1993; Wiedenbein 1993) following the international agreement on the Convention on Biodiversity at the Earth Summit in Rio de Janeiro in the previous year.
12 Gray, Murray 2011. Other nature: geodiversity and geosystem services. Environmental Conservation 38 (3): 271–274
13 Copyright © 2016 Ruimtemettoekomst.nl; see: http://www.ruimtemettoekomst.nl/wiki/wiki/ontwikkelconcepten/lagenbenadering/wiki/ondergrondlaag/ondergrondkwaliteiten-2
14 Action 5 of the EU Biodiversity Strategy to 2020 (COM(2011)244) calls Member States to map and assess the state of ecosystems and their services in their national territory with the assistance of the European Commission.

capital protocol are part of this. A dedicated Working Group has been established to oversee the implementation of Action 5 of the EU Biodiversity Strategy to 2020. Several pilots have been set up with voluntary participation of Member States experts. In 2015, a special pilot study was launched on soil services. The goals of this pilot are to[17]:

1. increase the awareness of the importance of soil services;
2. build capacity;
3. be policy-oriented;
4. enable an improvement of the knowledge base;
5. support EU policy frameworks.

Within the MAES Soil Pilot, an inventory has been made of the benefits of soil services. Indicators, data and knowledge necessary for the sustainable use of these services are also identified. The MAES Soil Pilot shows that the availability and quality of soil services is highly dependent on local circumstances.

Although a substantial amount of maps, assessments, tools and examples are available and shown in various EU data systems and projects (such as LUCAS, FADN, CORINE Land Cover, RECARE, LANDMARK, ECOFINDERS, DEMETER-tool, ISQAPER, EFESE), the MAES Pilot shows that this knowledge should still be made applicable for different scales, policies and private and public stakeholders.

There is already a substantial amount of maps, assessments, tools and examples of integration into policy making, which will be further strengthened by on-going research or demonstration projects. Through the use of spatial indicators to be integrated in assessment, an easy identification and reference of additional projects, good practices and lessons learned, enabling further development of the approach at various scales for various policies.

Narrative

A joint narrative supports the communication and understanding of the importance of the soil services for society. It is a basis for awareness building and connecting to the different stakeholders. This narrative addresses the current situation, the added value of soil services, the dilemma of the common goods and gives an introduction towards transition.

Current situation

Soil is subject to a series of degradation processes or threats. In its Soil Thematic Strategy[18] (STS), the EU focuses on soil protection and encompasses in a comprehensive way the major soil threats: erosion, decline in organic matter, local and diffuse contamination, sealing, compaction, decline in biodiversity, salinization, floods and landslides. In the STS soil degradation is stated as a serious problem, driven or exacerbated by human activity, such as inadequate agricultural and forestry practices, industrial activities, tourism, urban and industrial sprawl and construction works. These activities have a negative impact by preventing the soil from performing its broad range of functions and services to humans and ecosystems. This results in a loss of soil fertility, carbon stocks and biodiversity, lower water-retention capacity, disruption of gas and nutrient cycles and the reduced degradation of contaminants.

Threat or value creation?

A soil protection approach by itself cannot work without demonstrating the value of this precious resource and the benefits of sustainable soil management. Societal challenges cannot be met without a well-functioning soil system. The soil system can provide services to society, but these

15 EU, Mapping and Assessment of Ecosystems and their Services; An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020. Discussion paper – Final, April 2013
16 See http://ec.europa.eu/environment/nature/biodiversity/economics/
17 Mapping and assessment of soil-related ecosystem services pilot phase draft policy brief
18 COM(2006)231

services are not always consciously used. This can either lead to damage and costs or to under-use and not reclaimed benefits. Some examples:

- Unsustainable soil management may increase crop yields in the short term but in the long term may lead to a loss of organic matter causing a decrease in yield and a decrease of carbon sequestration. Balancing the organic matter content by sustainable management helps to achieve a sound moisture content, a balance in leaching of nutrients and carbon sequestration, thus optimizing irrigation, avoiding over-fertilization and mitigation of climate change.
- Unsustainable ground water management can lead to soil subsidence causing damage to (underground) infrastructure and greenhouse gas emission. Sustainable groundwater management can contribute to climate change mitigation and adaptation and to nature conservation.
- Ensuring the soil system functioning in urban areas by green spaces and minimum sealing, can help to buffer discharge of rain water thus attributing to climate change adaptation, avoiding costs for over dimension of sewer systems.

These examples show that sustainable use of soils leads to value creation. To optimize the contribution of soil services for private and societal use, a balance is needed between value protection and value generation. Instruments are needed to translate this concept into practise. A first step in this regard is to invest in approaches that enable the monitoring and assessment of the pressures on the EU's soil system capital and how these pressures affect the flow of soil system services to the economy and society.

Private and Common good?

Extensive evidence shows that most of the costs of soil degradation are not borne by the landowners or the immediate land users, instead they are often borne by society at large and by players far from the location of the problem (this is known as offsite costs). Due to private ownership, the benefits of soil services are only partly used. For example, farmers use their land only for food or biomass production, while by sustainable land management they can also contribute to drinking water availability and safety, bio and landscape diversity and carbon sequestration. By demonstrating that the multipurpose use of land entails multiple benefits, an added value is given to the soil services. Multipurpose use of soil also benefits to the society and contributes the EU societal challenges defined in the EU 2020 strategy agenda. Conscious and sustainable soil use and management can secure these benefits for future use, thus protecting the soil and its services. The stakeholders' needs have to be addressed and revenues should be shared. This is a transition from protection measures to fight threats towards a sustainable use and management to support the achievement of societal challenges. Management tools on EU, national, regional and local scale are therefore required. Land management tools are the key to define policy on sustainable use and management of the natural capital.

Towards a transition

The soil system cannot be treated as a "slave". It may not be depleted and left degraded, after all its gifts are consumed. On the other hand, a strong protection policy, as if the soil system is a "child", leaves the potential of the soil system to contribute to societal challenges unused and fails to appreciate its potential value. Therefore, the soil system should be considered as a "partner": A partner in (societal) development. A partnership shows the value of both partners, gives strength and requires investing in one another. It means that society uses the soil system in a sustainable way to contribute to societal challenges and invests in sustainable management by taking into account the local characteristics of the soil system. **The focus shifts from preventing and fighting threats towards a sustainable use and management and restoration of soil characteristics.** Those overarching principles should be defined at policy level.

The role of the authorities is not only to set the rules but also to facilitate development processes by providing a level playing field, guidance and knowledge, information and data. The implementation of these principles obviously requires an integrated and bottom-up process involving local stakeholders. The potential of the soil system is locally defined, users and stakeholders differ and not all soils can deliver all services. Multiple use needs to be fine-tuned according to local conditions for delivering the best value. The instruments needed for such a process change should be a combination of 'top-down' policy establishing overarching principles and tailor made 'bottom-up' solutions on different scales.

Multipurpose use of land for private and public benefits shows that a transition in policy and mindset is needed. Such a transition is a challenge and should start with awareness building combined with showcases or pilots.

Recommendations for transition

Based upon her narrative the MAES Soil pilot working group has the following recommendations:

Strategy and vision

A transition asks for long term public and private perspectives. MS, regions and municipalities, but also substantial land owners should be stimulated to draw up such a long-term vision. Multifunctional land use and a change from 2-dimensional, surface land management towards a 4/5-dimensional management of the soil system should be facilitated[19].

Awareness and capacity building

Value creation should be stimulated by connecting societal challenges with the soil system by showing examples. Training and capacity building for authorities on different levels is essential.

Organizing cooperation

Cooperation between public authorities and stakeholders must be organized at local, regional, national and European levels. Insight in barriers for multifunctional use helps to overcome these. Insight in stakeholder interests can help, not only to come to agreements and to share interests, but also to find common grounds to optimize multiple use.

Creating networks of practice

Creation of a network or Community of Practise on soil, land use and land management supports the transition by sharing experiences and best practices, raising awareness, development of instruments, sharing of data[20] (PM: Result of MAES) and knowledge. Such a network should connect with existing networks such as the Common Forum on contaminated land, the European Landowners' Organisation, Farmer organisations, Nicole, NGOs, citizen associations, cities platforms, MAES working group, joint programming initiatives as Facce, Water, Urban and Climate change, European Innovation Partnerships like EIP-Agri[21].

Facilitating with instruments, information and knowledge

Making better use of existing instruments and knowledge, creating tailor made (policy) instruments, sharing data and information and jointly develop knowledge. Knowledge gaps need to be identified and addressed strategically.

Agreement on data collection, data management and monitoring of the status of the soil system and the effects of management measures is crucial.

Monitoring

A shift from prevention towards sustainable should avoid damage to the soil system. Therefore monitoring of the effectivity of land management instruments is needed.

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19 A 4/5-D management takes into account the 3-dimensional system (the space taken in by the soil system, the surface and subsurface) a long term perspective (time) and the use and availability of data (5D)

20 Physical, chemical and biological data, socio economic data, land use and land cover data; data describing the soil system, effects on this system and data that give socio economic value.

21 The agricultural European Innovation Partnership (EIP-AGRI) works to foster competitive and sustainable farming and forestry that 'achieves more and better from less'. It contributes to ensuring a steady supply of food, feed and biomaterials, developing its work in harmony with the essential natural resources on which farming depends.

Annex III: Factsheets on relevant research projects

- INSPIRATION
- RECARE
- LANDMARK
- Renewing the impact assessment of land consolidation: the contribution of ecosystem services
- Land consumption in Italy
- LIFE SAM4CP
- LUCAS soil
- TEEB city tool
- URBAN SMS
- ENVASSO

PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
INSPIRATION	research project	*EU level*	*societal*
Integrated Spatial Planning, Land Use and soil management research action			

Countries covered by the project:	AT, BE, CH, CZ, DE, ES, FI, FR, IT, NL, PO, PT, RO, SE, SI, SK, UK
Start date: *1/03/2015*	**End date:** *28/02/2018*

PROJECT SUMMARY

Land is a limited resource. There are different – synergistic or competing – options how land can be used. Any use does impact our soil, sediment and water system to which the land is linked. A good understanding of these complex linkages is essential in order to steward land to a more sustainable future for Europe’s citizens and its global partners. Research contributes to facilitate sustainable land management and support evidence based policy making.

INSPIRATION (INtegrated Spatial PlannIng, land use and soil management Research AcTION) is a Coordination and Support Action funded by the European Commission in order to develop a Strategic Research Agenda (SRA) for Europe on soil, land use and land management.

INSPIRATION adopted a consequent bottom-up approach - aiming for a research agenda that is accepted by all societal groups in the EU member states. Therefore, creation of the SRA engaged diverse groups represented by national key stakeholders (NKS) coming from funders (public and private), knowledge producers, end users of research and NGO’s in the 17 participating INSPIRATION countries. Land-use and soil related research demands from their perspectives were collated into the SRA in five clusters. The clusters are societal demands, natural capital supply, land management, net-impacts from local to global scale, and cross-cutting integrated research topics. More than 500 experts collated the SRA in an iterative process towards 39 research topics under these five clusters. Many topics relate to soil related ecosystem services and identify the practical knowledge needs.

INSPIRATION supports scoping out models for funding and implementing the SRA. We convene and consult with groups of policy makers, research funders, end users and knowledge creators/ disseminators from both within the EU and beyond. We support funders to identify research activities on which they would like to collaborate in common (inter)national calls to create co-funding and stimulate match-making between potential funders through National Contact Points.

PROJECT KEYWORDS

SOCIETAL CHALLENGES, SPATIAL PLANNING, LAND USE, SOIL SYSTEMS MANAGEMENT, STRATEGIC RESEARCH AGENDA, INNOVATION

Soil functions addressed (STS)	ECOSYSTEM GROUPS ADDRESSED (MAES)
☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)	
☒ CARBON STORAGE (INCL. CLIMATE REGULATION)	☒ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)	☒ FOREST ECOSYSTEMS
☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)	☒ FRESHWATER ECOSYSTEMS
☒ NUTRIENT CYCLING	☐ MARINE ECOSYSTEMS
☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)	☒ URBAN ECOSYSTEMS
☒ SOIL RELATED CULTURAL SERVICES (INCL. CULTURAL HERITAGE)	

PROJECT OUTPUTS

HTTP://WWW.INSPIRATION-AGENDA.EU/

The process of finalizing INSPIRATION's Strategic Research Agenda was ongoing when this template was drafted. The potential impact of the SRA can be tremendous. A broad variety of stakeholders identified their research needs as input for the SRA. Therefore, the scope of research topics and the questions that were collected shaped a truly multi-stakeholder-based research agenda. It will merge individual requirements of EU Member States and bottom-up collected research demands of stakeholders into a consistent SRA. The level of integration of soil and land use related topics is remarkable. The SRA blends research on soil quality, land use and land management issues, both in urban and in rural areas. This is unique, particularly because of its ambition: Structuring research areas towards balancing the demand for and supply of resources and natural capital and reducing the ecological footprint by proper land management methods and tools. The ecosystem services concept has been a key element in this endeavour.

Many transnational research questions that can be addressed through cofounding. Many knowledge gaps still exist, among others on mapping and assessment of soil related ecosystem services.

With the final public release of the SRA forthcoming, matchmaking with national funding institutions and elaborating implementation models for the SRA are the most challenging remaining tasks for the project. However, the final SRA is expected to be the first milestone in a paradigm shifting process of land and soil-based research policy towards multi-national and stakeholder-oriented research funding.

more information

HTTP://WWW.INSPIRATION-H2020.EU/

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PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
RECARE	research project	*EU level*	*stakeholder tools*
Preventing and remediating degradation of soils in Europe through land care			
Countries covered by the project: Switzerland, Portugal, Cyprus, Greece, Denmark, Poland, Spain, Iceland, Norway, Slovakia, Netherlands, Sweden, Italy, Romania, United Kingdom			
Start date: *1/11/2014* **End date:** *31/10/2018*			

PROJECT SUMMARY

Although there is a large body of knowledge available on soil threats in Europe, this knowledge is fragmented and incomplete, in particular regarding the complexity and functioning of soil systems and their interaction with human activities. The main aim of RECARE is 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 will be assessed using a new methodology, based on the WOCAT mapping procedure, ii) impacts of degradation and conservation on soil functions and ecosystem services will be quantified in a harmonized, spatially explicit way, accounting for costs and benefits, and possible trade-offs, iii) prevention, remediation and restoration measures selected and implemented by stakeholders in a participatory process will be evaluated regarding efficacy, and iv) the applicability and impact of these measures at the European level will be 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 will be reviewed and compared to identify potential incoherence, contradictions and synergies. Policy messages will be 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, will accompany 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.

PROJECT KEYWORDS

SOIL THREATS; SOIL DEGRADATION; SOIL FUNCTIONS; SOIL ECOSYSTEM SERVICES; PREVENTION, REMEDIATION AND RESTORATION MEASURES; LAND CARE; SUSTAINABLE LAND MANAGEMENT; CONSERVATION; POLICY RECOMMENDATIONS

Soil functions addressed (STS)	ECOSYSTEM GROUPS ADDRESSED (MAES)
☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)	
☒ CARBON STORAGE (INCL. CLIMATE REGULATION)	☒ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)	☒ FOREST ECOSYSTEMS
☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)	☒ FRESHWATER ECOSYSTEMS
☒ NUTRIENT CYCLING	☐ MARINE ECOSYSTEMS
☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)	☒ URBAN ECOSYSTEMS
☒ SOIL RELATED CULTURAL SERVICES (INCL. CULTURAL HERITAGE)	

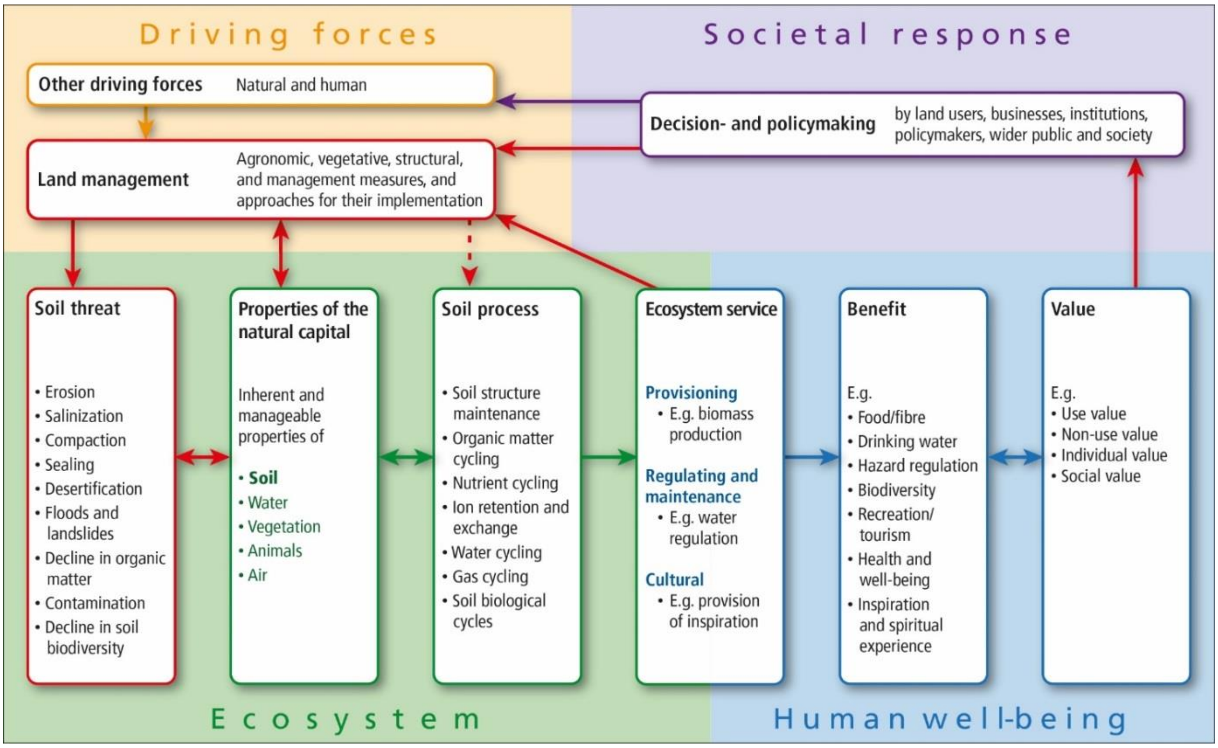
PROJECT OUTPUTS

1. Assessment report of soil threats in europe with status, methods, drivers, key indicators of soil threats, and impacts on ecosystem services: [1] j. Stolte, m. Tesfai, j. Keizer, l. Øygarden, s. Kværnø, f. Verheijen, p. Panagos, c. Ballabio, and r. Hessel, "soil threats in europe," 2016. Jrc scientific and technical reports, 206 pp.

Table 14.14: Soil threats impact on soil functions, categorized in classes low, medium and large reflected by the size of the dots. Red means negative effect, green positive.

	Biomass production	Storing/filtering/transforming	Gene pool (biodiversity)	Physical basis	Raw materials	Cultural heritage
Water erosion	● medium red		● large red	● large red	● medium red	● small red
Wind erosion	● medium red	● small red				
SOM decline peat	● small red / ● medium green	● large red	● large red		● small red	● large red
SOM decline mineral	● large red	● large red	● medium red			
Compaction	● large red	● large red	● small red			
Sealing	● large red	● large red	● large red	● large green	● medium green	● medium red / ● small green
Contamination	● large red	● medium red	● large red			
Salinization	● large red	● small red	● large red	● small red		● small red
Desertification	● large red	● large red	● large red	● small red	● small red	● small red
Landslides and flooding	● medium red / ● small green	● small red	● small red	● medium red	● small red	● small red
Biodiversity decline	● large red	● large red	● large red	● large red	● large red	● large red

2. Framework for the operationalising ecosystem services for the mitigation of soil threats:
Schwilch, g., bernet, l., fleskens, l., giannakis, e., leventon, j., marañón, t., mills, j., short, c., stolte, j., van delden, h., verzandvoort, s., 2016. Operationalizing ecosystem services for the mitigation of soil threats: a proposed framework. Ecological indicators 67: 586-597 (http://dx.doi.org/10.1016/j.ecolind.2016.03.016)

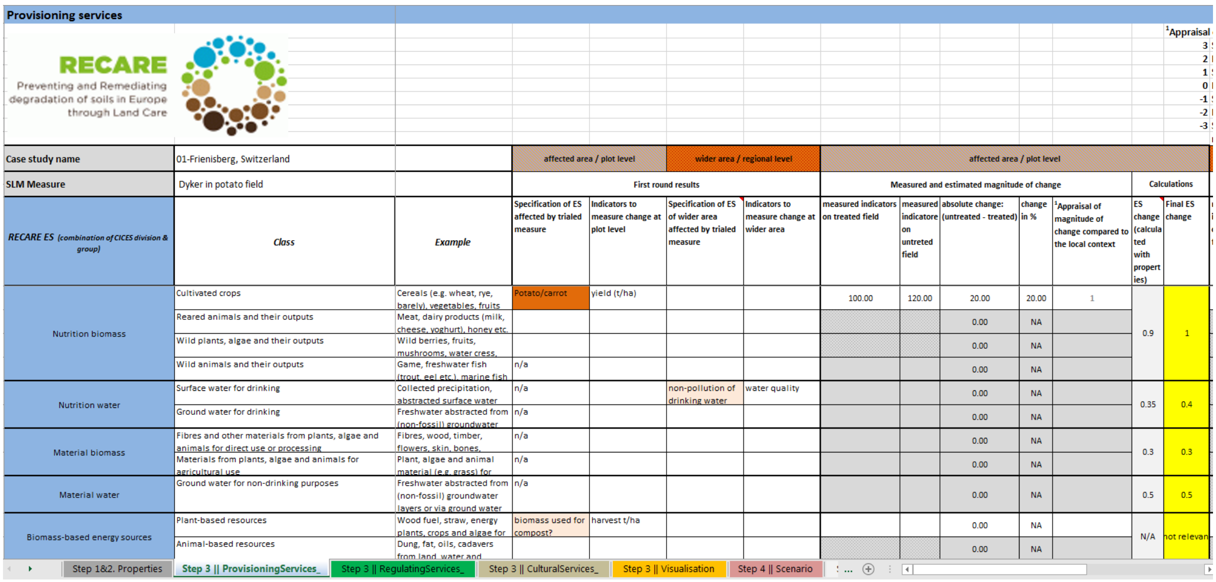


3. Wocat mapping methodology

This method enables mapping of land degradation phenomena and conservation efforts, and of impacts of land degradation and conservation on ecosystem services (productive, ecological and socio-cultural, with sub-categories). The method was applied to the 17 case studies in europe.

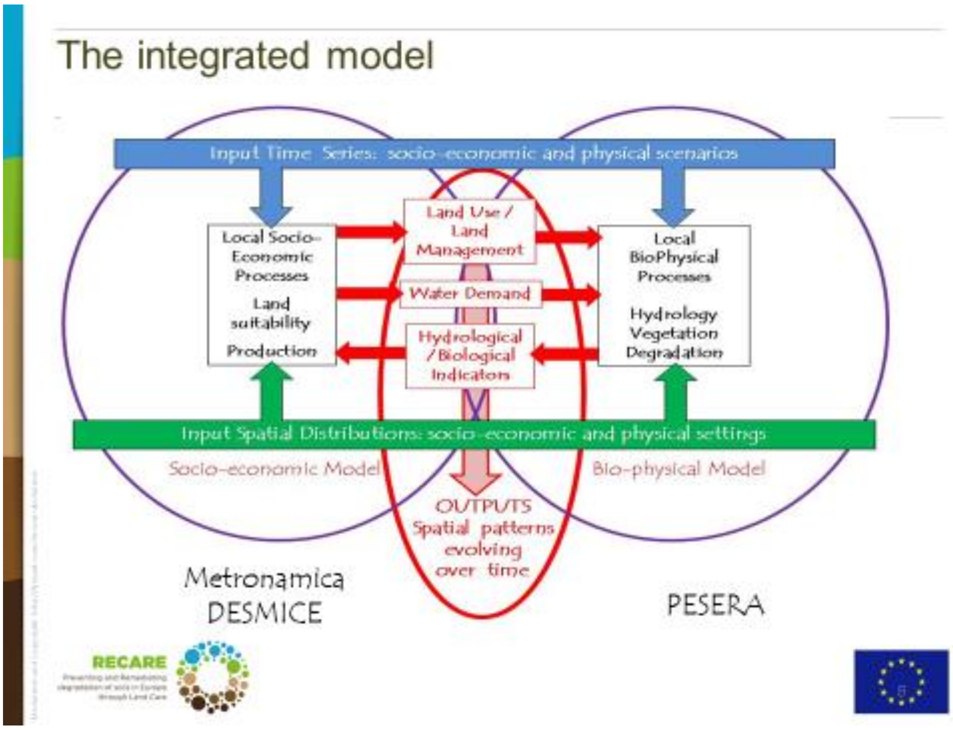
http://www.recare-project.eu/downloads-by-category/public-documents/project-deliverables/343-report-08-d3-2-report-on-current-state-of-degradation-and-conservation-isric-full/file

4. A tool to assess the impacts of sustainable land management measures on ecosystem services (at field and regional level)



Case study name	01-Frienisberg, Switzerland		affected area / plot level		wider area / regional level		affected area / plot level						
SLM Measure	Dyker in potato field		First round results				Measured and estimated magnitude of change					Calculations	
RECARE ES *(combination of CICES division & group)*	*Class*	*Example*	Specification of ES affected by trialed measure	Indicators to measure change at plot level	Specification of ES of wider area affected by trialed measure	Indicators to measure change at wider area	measured indicators on treated field	measured indicatore on untreted field	absolute change: (untreated - treated)	change in %	[1]Appraisal of magnitude of change compared to the local context	ES change (calculated with properties)	Final ES change
Nutrition biomass	Cultivated crops	Cereals (e.g. wheat, rye, barely), vegetables, fruits	Potato/carrot	yield (t/ha)			100.00	120.00	20.00	20.00	1	0.9	1
	Reared animals and their outputs	Meat, dairy products (milk, cheese, yoghurt), honey etc.							0.00	NA			
	Wild plants, algae and their outputs	Wild berries, fruits, mushrooms, water cress,							0.00	NA			
	Wild animals and their outputs	Game, freshwater fish (trout, eel etc.), marine fish	n/a						0.00	NA			
Nutrition water	Surface water for drinking	Collected precipitation, abstracted surface water	n/a		non-pollution of drinking water	water quality			0.00	NA		0.35	0.4
	Ground water for drinking	Freshwater abstracted from (non-fossil) groundwater	n/a						0.00	NA			
Material biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Fibres, wood, timber, flowers, skin, bones,	n/a						0.00	NA		0.3	0.3
	Materials from plants, algae and animals for agricultural use	Plant, algae and animal material (e.g. grass) for	n/a						0.00	NA			
Material water	Ground water for non-drinking purposes	Freshwater abstracted from (non-fossil) groundwater layers or via ground water	n/a						0.00	NA		0.5	0.5
Biomass-based energy sources	Plant-based resources	Wood fuel, straw, energy plants, crops and algae for	biomass used for compost?	harvest t/ha					0.00	NA		N/A	hot relevan
	Animal-based resources	Dung, fat, oils, cadavers from land, water and							0.00	NA			

5. Integrated assessment model for simulating impacts of externalities, policy and management options on a number of ess indicators relevant to the range of soil threats in europe



6. Policy impact assessment of existing eu and national soil-related policies to identify potential incoherence, contradictions and synergies among policies. Impacts partly refer to es. Ongoing.

Indicate lessons learned, knowledge gaps encountered, expected developments

Project is still ongoing.

A knowledge gap that RECARE is trying to fill is to infer how much of a change in an ecosystem service is brought about by changes in the soil quality, properties or soil processes which are modified by SLM measures. And then to value these changes in ESS (pros and contras) with stakeholders in order to decide on which types of land management to pursue.

more information

WWW.RECARE-PROJECT.EU

WWW.RECARE-HUB.EU

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PROJECT DATA

PROJECT NAME AND DURATION		PROJECT TYPE	CONTEXT	INTENDED USERS
LANDMARK		research project	*EU level*	*stakeholder tools*
LAND MANAGEMENT: ASSESSMENT, RESEARCH KNOWLEDGE BASE				
Countries covered by the project:	22			
Start date: *1/05/2015*	**End date:** *1/10/2019*			

PROJECT SUMMARY

LANDMARK is a pan-European multi-actor consortium of leading academic and applied research institutes, chambers of agriculture and policy makers that will develop a coherent framework for soil management aimed at sustainable food production across Europe.

The LANDMARK proposal 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.

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: 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 that either address the management & assessment of individual soil functions, or address multiple soil functions, but only at local scales. 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.

PROJECT KEYWORDS

ECOSYSTEM SERVICES PROVIDED BY SOILS, FUNCTIONAL LAND MANAGEMENT, MULTI-FUNCTIONALITY OF SOILS, BEST MANAGEMENT PRACTICES (BMPS), SOIL MONITORING, SUSTAINABLE INTENSIFICATION OF AGRICULTURE, FOOD SECURITY, ENVIRONMENTAL POLICY FRAMEWORK

Soil functions addressed (STS)

- ☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)
- ☒ CARBON STORAGE (INCL. CLIMATE REGULATION)
- ☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)
- ☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)
- ☒ NUTRIENT CYCLING
- ☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)
- ☐ SOIL RELATED CULTURAL SERVICES (INCL. CULTURAL HERITAGE)

ECOSYSTEM GROUPS ADDRESSED (MAES)

- ☒ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
- ☒ FOREST ECOSYSTEMS
- ☐ FRESHWATER ECOSYSTEMS
- ☐ MARINE ECOSYSTEMS
- ☐ URBAN ECOSYSTEMS

PROJECT OUTPUTS

MODELS: DEXI QUALITATIVE DECISION MODELS (FOR EACH OF THE 5 SOIL FUNCTIONS), DATA MINING REGRESSION MODEL (FOR EACH OF THE 5 SOIL FUNCTIONS), BAYESIAN BELIEF MODEL TO DEVELOP DEMAND AND SUPPLY MAPS FOR THE 5 SOIL FUNCTIONS FOR EUROPE, GIAGNOSTIC FEATURES MODEL (WP2);

METHODOLOGY/MODEL: LOGICAL SIEVE PLUS SOIL FUNCTIONS RESPONSE CURVES

TOOLS: SOIL NAVIGATOR (PILLAR 1 LOCAL SCALE)

MAPS (INCLUDE VISUAL EXAMPLE): AVAILABLE END 2018 FOR EACH FUNCTION

REPORTS DEVELOPED FOR MAPPING AND ASSESSMENT : REGARDING MAPPING WP3 AND WP4 REPORTS FORESEEN FOR 2018-2019 . WHILE PILLAR 1(LOCAL), PILLAR 2(REGIONAL/NATIONAL) AND PILLAR 3 (EU) REPORT FORESEEND BY END OF THE PROJECT OCT 2019

Indicate lessons learned, knowledge gaps encountered, expected developments

at the moment august 2017 info available:

wp1.2

https://landmark2020.bitrix24.com/docs/pub/aa0dda1bce19164c96321d1257d694b6/default/?&

pillar3 http://www.mdpi.com/2071-1050/9/3/407

project in general http://blog.globalsoilbiodiversity.org/article/2017/03/22/supply-soil-functions-european-soils

more information

INDICATE LINKS TO PROJECT WEBSITE, ONLINE AVAILABLE PROJECT OUTPUT

LINKS WEBSITE WWW.LANDMARK2020.EU

ALL PUBLICATIONS ARE AVAILABLE AND REACHABLE HERE

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DELIVERABLES HTTP://LANDMARK2020.EU/LIST-OF-DELIVERABLES/ AND PRODUCTS FOR EACH WP:

HTTP://LANDMARK2020.EU/WORK-PACKAGE/WORK-PACKAGE-1/

HTTP://LANDMARK2020.EU/WORK-PACKAGE/WORK-PACKAGE-2/

HTTP://LANDMARK2020.EU/WORK-PACKAGE/WORK-PACKAGE-3/

HTTP://LANDMARK2020.EU/WORK-PACKAGE/WORK-PACKAGE-4/

HTTP://LANDMARK2020.EU/WORK-PACKAGE/WORK-PACKAGE-5/

HTTP://LANDMARK2020.EU/WORK-PACKAGE/WORK-PACKAGE-6/

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PROJECT DATA

PROJECT NAME AND DURATION	1.5 YEAR	PROJECT TYPE	CONTEXT	INTENDED USERS
Type project acronym		research project	*regional level*	*policy*
Renewing the impact assessment of land consolidation: the contribution of ecosystem services				
Countries covered by the project:	Belgium (Wallonia)			
Start date: *1/03/2015*	**End date:** *1/09/2016*			

PROJECT SUMMARY

The use of ESS approach in land consolidation plan is a practical application of an integrated Ecosystem Services valuation framework to inform decision and contribute to land planning at the local scale. The project aims to develop a methodology for impact assessments of land-consolidation plans based on ES. This methodology is directly applied on the land-consolidation plan of three municipalities in Wallonia (Fernelmont, Eghezée and Wasseiges). After predefining a list of locally relevant ESS and a typology of ecosystems, biophysical and social valuations are carried out. The social valuation comprises two steps: ranking of the most important ESS according to stakeholders through a methodology based on focus groups, the Delphi and "management by consent" methods; and participatory mapping of the perception of the supply and of the demand of these most important ES, with a specific focus on cultural ESS. The biophysical valuation includes mapping and quantification of ESS based on indicators obtained from a hydrological model, and scenario development of potential ESS supply. Participatory comparison of ESS supply and demand will then guide land-consolidation actions. Following the development and test of the methodology, operational tools will be produced and public-service agents will be trained to mainstream the use of ES-based methodology to assess impacts of land consolidation plans on the multifunctionality of rural landscapes.

PROJECT KEYWORDS

IMPACT ASSESSMENT, LAND CONSOLIDATION, LAND USE PLANNING, FACILITIES

Soil functions addressed (STS)	ECOSYSTEM GROUPS ADDRESSED (MAES)
☐ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)	☐ **AGROECOSYSTEMS (CROPLAND, GRASSLAND)**
☐ CARBON STORAGE (INCL. CLIMATE REGULATION)	☐ FOREST ECOSYSTEMS
☐ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)	☐ FRESHWATER ECOSYSTEMS
☐ **WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)**	☐ MARINE ECOSYSTEMS
	☐ URBAN ECOSYSTEMS

☐ NUTRIENT CYCLING

☐ **SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)**

☐ **SOIL RELATED CULTURAL SERVICES (INCL. CULTURAL HERITAGE)**

PROJECT OUTPUTS

REPORTS, MAPS, PRESENTATIONS, TRAINING SESSION

More dynamic approach than conventional strategic environmental assessment (participation and scenarios)

Impact assessment and the project conception could be merged.

Indicators objectivated the discussions.

New tests to be done (reallotment scheme, another LC projet)

Future uses of the methodology : ex-ante/post assessment

more information

PROCEEDINGS OF THE SYMPOSIUM ON LAND CONSOLIDATION AND READJUSTMENT FOR SUSTAINABLE DEVELOPMENT (APELDOORN, NL, 9-11/2016) : HTTP://WWW.OICRF.ORG/DOCUMENT.ASP?ID=16601

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PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
Land Consumption in Italy	*Institutional task / environmental monitoring reporting*		*POLICY MAKERS, PUBLIC BODIES, REGIONS, MUNICIPALITIES, ENVIRONMENTAL PROTECTION INSTITUTIONS*
Mapping and Assessment of Soil Ecosystem Services at national level in Italy			
Countries covered by the project:	ITALY		
Start date: *2014*	**End date:** AS LONG AS POSSIBLE		

PROJECT SUMMARY

ISPRA and the Italian National System for the Protection of the Environment analysed and mapped nine ecosystem services (Carbon Storage and Sequestration, Habitat Quality, Crop Production, Timber Production, Water Purification, Erosion Protection, Pollination, Microclimate Regulation, Particulate and Ozone Removal) and their link with agricultural and natural soil loss due to artificial land cover development. The assessment was achieved from both biophysical and economic point of view, using, only for five, InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs; AA.VV., 2015) models. Results are published in the National Report on land consumption which is published every year by ISPRA.

PROJECT KEYWORDS

LAND USE, LAND COVER, LAND DEGRADATION, SPRAWL, SOIL SEALING, LAND CONSUMPTION,

Soil functions addressed (STS)	ECOSYSTEM GROUPS ADDRESSED (MAES)
X Provision of goods (biomass, fuel, pharmaceuticals, construction materials)	X Agroecosystems (cropland, grassland)
X Carbon storage (incl. climate regulation)	X Forest ecosystems
X Water purification (and soil contaminant	X Freshwater ecosystems

reduction)

X Water flows regulation (incl. sediment production)

☐ Nutrient cycling

☐ Support for biodiversity (incl. genetic resources)

☐ Soil related cultural services (incl. cultural heritage)

X Habitat Quality

X Crop Production

X Timber Production

X Pollination

X Microclimate Regulation

X Particulate and Ozone Removal

☐ Marine ecosystems

X Urban ecosystems

PROJECT OUTPUTS

ECOSYSTEM SERVICE	MINIMUM VALUE [€/YEAR]	MIDDLE VALUE [€/YEAR]	MAXIMUM VALUE [€/YEAR]
Carbon Storage and Sequestration	-14.548.507	-73.348.723	-132.148.938
Habitat Quality	-11.146.847	-11.146.847	-11.146.847
Crop Production	-412.049.834	-412.049.834	-412.049.834
Timber Production	-15.665.938	-15.665.938	-15.665.938
Water Purification	-33.060.912	-110.995.495	-188.930.078
Erosion Protection	-3.195.550	-3.731.128	-4.266.706
Pollination	-1.830.676	-4.576.690	-7.322.703
Microclimate Regulation	-132.918.045	-132.918.045	-132.918.045
Particulate and Ozone Removal	-1.129.569	-2.304.998	-3.480.426
Totale	**-625.545.878**	**-766.737.697**	**-907.929.515**

TABLE 1: ESTIMATE OF THE MINIMUM AND MAXIMUM ANNUAL COSTS DUE TO THE INCREASE OF ARTIFICIAL LAND COVER (LAND CONSUMPTION) OCCURRED BETWEEN 2012 AND 2016 IN ITALY.

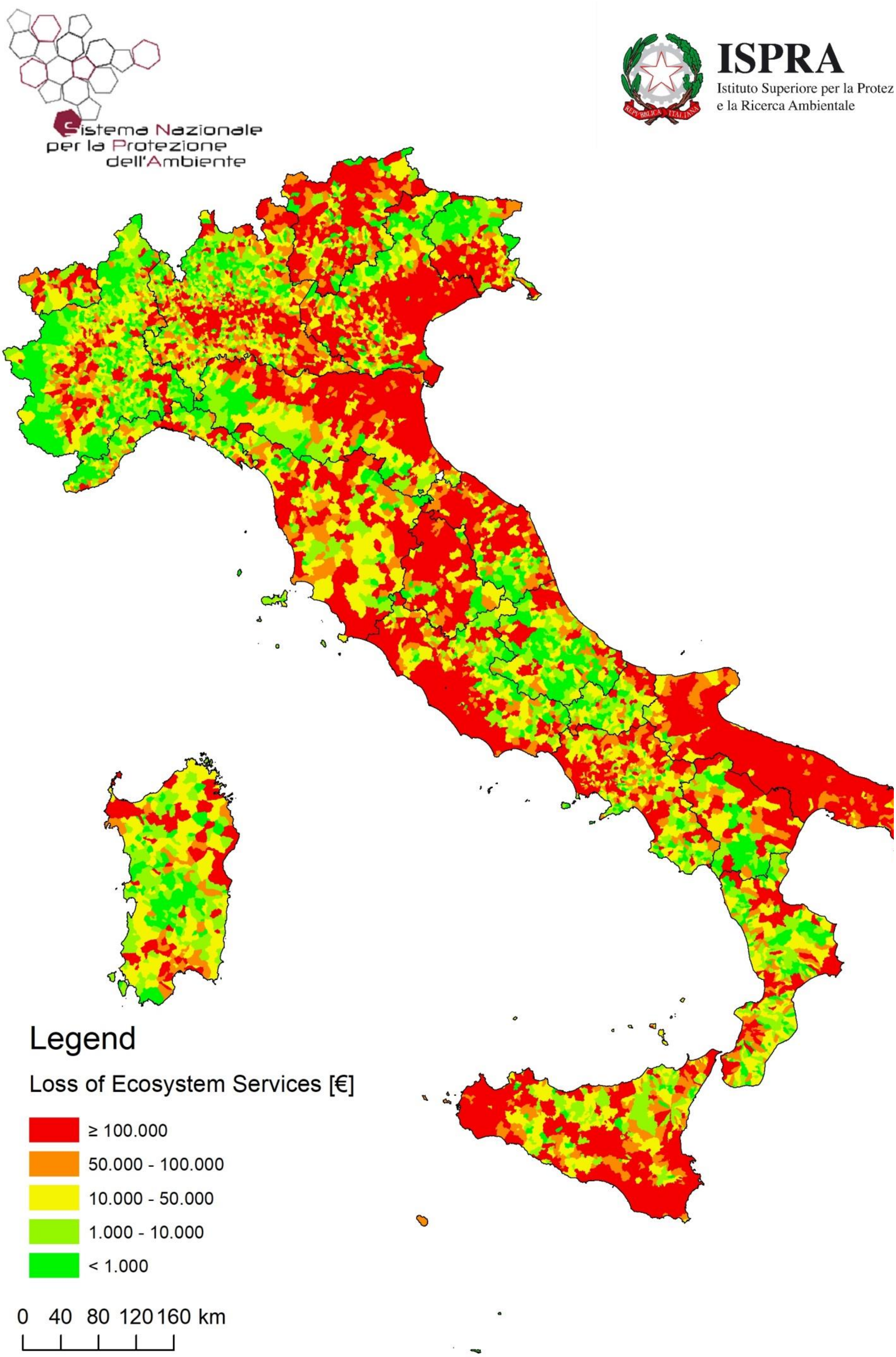

FIGURE 1: MAPPING OF THE ECONOMIC COSTS ASSOCIATED TO THE LOSS OF ECOSYSTEM SERVICES (TOTAL COSTS) DUE TO SOIL CONSUMPTION BETWEEN 2012 AND 2016, IN EURO PER YEAR FOR THE MUNICIPALITY

Willingness of data

more information

FOR ANY FURTHER INFORMATION, ALL DATA ARE PUBLISHED ON ISPRA'S WEB-SITE :

HTTP://WWW.ISPRAMBIENTE.GOV.IT/IT

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PROJECT DATA

SOIL ADMINISTRATION MODEL

FOR COMMUNITY PROFIT

03-JUN-2014 TO 30-JUN -2018	PROJECT TYPE	CONTEXT	INTENDED USERS
LIFE SAM4CP	case study	*local level*	*stakeholder tools*

SOIL ADMINISTRATION MODEL

FOR COMMUNITY PROFIT

Countries covered by the project: Italy

Start date: *3/06/2014* **End date:** *30/06/2018*

PROJECT SUMMARY

The LIFE SAM4CP project aims to create an easy-to-use simulator that will allow territorial decision makers to include the ecological functions of soil within the assessment of the environmental and economic costs and benefits associated with possible urban planning and land-use measures and choices. The simulator will allow different territorial transformation scenarios to be assessed according to the seven main ecological functions provided by soil in order to integrate these functions – and their potential gain or loss – into the decision-making process. The tool aims to help avoid land-use decisions that disproportionately reduce soil functions. It also aims to enable a proper evaluation of the potential costs and benefits of specific measures aimed at reducing soil sealing. It will be used to help draft a municipal land-use plan to preserve the ecosystem services provided by soils.
The project hopes to demonstrate how use of the tool and integration of soil conservation considerations into the decision-making process can protect ecological functions for the benefit of the local community. It expects to demonstrate a significant reduction of soil sealing as well as overall economic savings thanks to the preservation of natural resources and restoration of the benefits provided by good quality soils.

PROJECT KEYWORDS

Land use change, land take, soil ecosystem services, sustainability, community

Soil functions addressed (STS)	ECOSYSTEM GROUPS ADDRESSED (MAES)
☒ Provision of goods (biomass, fuel, pharmaceuticals, construction materials)	☒ Agroecosystems (cropland, grassland)
☒ Carbon storage (incl. climate regulation)	☒ Forest ecosystems
☒ Water purification (and soil contaminant reduction)	☐ Freshwater ecosystems
☒ Water flows regulation (incl. sediment	☐ Marine ecosystems
	☒ Urban ecosystems

production)

☐ Nutrient cycling

☒ Support for biodiversity (incl. genetic resources)

☐ Soil related cultural services (incl. cultural heritage)

PROJECT OUTPUTS

The LIFE project SAM4CP aims to connect the scientific knowledge on ESS allowing a better territorial decision mechanism. The project leads to include the ecological assessment of soil within its economic value, also accounting alternative land-use scenario. This require a high degree “mapping” ESS knowledge, using accurate and precise dataset to support traditional environmental analysis for land use planning (InVEST software).

LIF£E SAM4CP aims at pursuing 6 main objectives:

1) Demonstrate as a territorial planning, which envisages in its own decisional processes an evaluation of the environmental benefits ensured by free soil, allows to the community a sizeable reduction of soil consumption and an overall saving thanks to the safety of the natural resources and of the public finances;

2) Enhancing and integrating the 7 main functions (carbon’s sequestration, bio-diversity, water purification, soil erosion, woody production, pollination, agricultural output) which are provided for free by the soil in the governance of the territory in order to reduce the soil consumption;

3) Safeguarding and ensuring a sustainable use of the soil, by highlighting the negative effects of the soil consumption in terms of an environmental evaluation of a territory;

4) Maintaining and enhancing the overall eco-systemic functions of the soil provided for free to the community;

5) Avoiding the public costs for the restoration of the eco-systemic functions provided by the soil, as well as the costs for the maintenance of the territory;

6) Safeguarding the agricultural functions of the soil by maintaining unchanged the other functions.

The analysis of ESS improves the ability of politicians, administrators, planners and stakeholders to define strategies of regeneration, ecologically and energy efficient oriented. Furthermore, it allows to reflect about the sustainability of urbanization and related environmental issues, bringing attention to social and economic aspects, too. The soil, as measurable value common good, requires a strong reduction of its consumption and a good use of it.

Bringing a ESS knowledge approach into planning practices means to improve the performances of land use resilient strategies, here intended as the possibility to achieve a long term land use efficiency by planning practices. If resilience is the capability of a city to adapt to any external intervention, both man-made or caused by climate change, in order to restore its own balance, then a indicator-based approach of the tradeoff among different soil function helps planners and administrators to reduce discretionary variables during decision-making phase.

more information

Visit:

http://www.sam4cp.eu/en/

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PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
LUCAS	Monitoring programme	*EU level*	*policy*

Soil component of the Land Use/Cover Area frame statistical Survey

Countries covered by the project:	EU plus Croatia, Albania, Bosnia-Herzegovina, Republic of Macedonia, Montenegro, Serbia and Switzerland
Start date: *2009*	**End date:** *ongoing*

PROJECT SUMMARY

It is a EU-wide soil monitoring 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. It covers all EU countries and recently Croatia, Albania, Bosnia-Herzegovina, Republic of Macedonia, Montenegro, Serbia and Switzerland. Currently involves approx. 260 thousand permanent monitoring locations. Since the first edition topsoil samples have been analyzed 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, planned for 2018, will also cover 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 will be available at the middle of 2018.

PROJECT KEYWORDS

LAND USE, CROPS, SOIL PARAMETERS, SOIL ORGANIC CARBON, SOIL MAPPING

Soil functions addressed (STS)

- ☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)
- ☒ CARBON STORAGE (INCL. CLIMATE REGULATION)
- ☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)
- ☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)
- ☒ NUTRIENT CYCLING
- ☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)
- ☐ SOIL RELATED CULTURAL SERVICES (INCL.

ECOSYSTEM GROUPS ADDRESSED (MAES)

- ☒ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
- ☒ FOREST ECOSYSTEMS
- ☐ FRESHWATER ECOSYSTEMS
- ☐ MARINE ECOSYSTEMS
- ☐ URBAN ECOSYSTEMS

CULTURAL HERITAGE)

PROJECT OUTPUTS

THE REPORT "LUCAS TOPSOIL SURVEY: METHODOLOGY, DATA AND RESULTS", COVERING 2009 RESULTS, HAVE BEEN PUBLISHED. SOIL DATABASE WITH ACCESS TO SINGLE LOCATIONS DATA, REPRESENTING 2009 EDITION, HAVE BEEN RELEASED TO PUBLIC WHEREAS ANALYSES OF SAMPLES COLLECTED DURING 2015 ARE ONGOING AND DATA WILL BE AVAILABLE AT THE MIDDLE OF 2018.

Information on the regional variability and updated maps of soil organic carbon, soil pH, clay, nutrient availability, etc. across Europe

MORE INFORMATION

HTTPS://ESDAC.JRC.EC.EUROPA.EU/ESDB_ARCHIVE/EUSOILS_DOCS/OTHER/EUR26102EN.PDF
•BALLABIO C., PANAGOS P., MONTANARELLA L. MAPPING TOPSOIL PHYSICAL PROPERTIES AT EUROPEAN SCALE USING THE LUCAS DATABASE (2016) GEODERMA, 261 , PP. 110-123.

Indicate contact person(s) name, phone, email, post address:
JRC in Ispra;

PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
TEEB city tool	research project	*local level*	*stakeholder tools*

Further development of the urban planning support tool 'TEEB city tool', on valuation of natural capital and ecosystem services (green and water) in cities

Countries covered by the project: NL

Start date: *1/07/2016* **End date:** *31/12/2018*

PROJECT SUMMARY

In the context of the urban agenda to strengthen growth, innovation and livability of cities and supported by the national government, seven Dutch cities agreed upon collaboration with knowledge institutions, consultancies, a gardeners association and citizen groups. In 2016, they signed an agreement to dedicate themselves to accelerating the further development and use of the so-called TEEB-city tool. This tool enables integration of health and well-being, climate change adaptation, water management, biodiversity and other potential benefits of nature based solutions into the urban planning process. Planners, city authorities, developers, companies and citizen groups have free access to this tool with which enables them to calculate and understand the value of green and blue infrastructures in their neigbourhoods.
An ambitious Community of Practice (CoP) has developed around this tool. By using the experience of the participating cities and the growing evidence on the impact of nature based solutions, they want to further develop the TEEB-city tool, thus bridging the gap between science, policy and practice.
Stakeholder participation and co-creation of urban plans will increase the sustainability and effectiveness of nature-based interventions. In the context of the Dutch Atlas of Natural Capital, the TEEB-city tool is now progressing towards a dynamic 3D knowledge platform as interface between stakeholders in urban planning and the scientific state-of-the-art, creating a level playing field.

PROJECT KEYWORDS

NATURAL CAPITAL, ECOSYSTEM SERVICES, VALUATION, NATURE BASED SOLUTIONS, URBAN PLANNING, PARTICIPATION, CO-CREATION,

Soil functions addressed (STS)

- ☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)
- ☒ CARBON STORAGE (INCL. CLIMATE REGULATION)
- ☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)
- ☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)

ECOSYSTEM GROUPS ADDRESSED (MAES)

- ☐ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
- ☐ FOREST ECOSYSTEMS
- ☐ FRESHWATER ECOSYSTEMS
- ☐ MARINE ECOSYSTEMS
- ☒ URBAN ECOSYSTEMS

☒ NUTRIENT CYCLING
☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)
☒ SOIL RELATED CULTURAL SERVICES (INCL. CULTURAL HERITAGE)

PROJECT OUTPUTS

TEEB CITY TOOL: WWW.TEEBSTAD.NL (IN DUTCH). REPORTS FOR MAPPING AND ASSESSMENT: VIELER K (2015) MAPPING NATURAL CAPITAL AND ECOSYSTEM SERVICES. MSC THESIS. RIVM, BILTHOVEN, UNIVERSITY OF UTRECHT, VAN WIJNEN HJ, RUTGERS M, SCHOUTEN AJ, ET AL. (2012) HOW TO CALCULATE THE SPATIAL DISTRIBUTION OF ECOSYSTEM SERVICES ACROSS THE NETHERLANDS. SCIENCE OF THE TOTAL ENVIRONMENT 415: 49-55, RUTGERS M, SCHOUTEN T, BLOEM J, ET AL. (2014) EEN INDICATORSYSTEEM VOOR ECOSYSTEEMDIENSTEN VAN DE BODEM: LIFE SUPPORT FUNCTIONS REVISITED. REPORT 2014-0145, RIVM, BILTHOVEN, OTHERS UNDER CONSTRUCTION.

Indicate lessons learned, knowledge gaps encountered, expected developments:
Cities feel the need to valuate natural capital, ecosystem services and nature based solutions, but are unable to sufficiently quantify and visualize these values in the process of political decision making. Multiple knowledge gaps exist on the contribution of natural systems to the well-being and prosperity of city inhabitants. Due to climate change and increased pressures on cities, the need for 'green' solutions will increase, including the knowledge base to make wise decisions.

MORE INFORMATION

INDICATE LINKS TO PROJECT WEBSITE, ONLINE AVAILABLE PROJECT OUTPUTS: SEE ABOVE

Indicate contact person(s) name, phone, email, post address:
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PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
URBAN-SMS	research project	*EU level*	*stakeholder tools*
Urban Soil Management Strategy			

Countries covered by the project:	Germany, Austria, Poland, Italy, Slovenia, Czech Rep., Slovakia
Start date: *1/10/2008*	**End date:** *1/03/2012*

PROJECT SUMMARY

URBAN SMS was a project under Central Europe program involving 11 partners from 7 countries, representing municipalities, agencies and research institutes. The objective of the project was to develop and implement a comprehensive soil management strategy for Central European municipalities helping urban planners to consider the value of soils and their different functions within the planning process. In detail it covered such specific goals as developing tools and instruments of urban soil management, implementing and testing them in pilot regions, producing an European transnational strategy towards sustainable urban soil management.

PROJECT KEYWORDS

SOIL SEALING, LAND TAKE, RAISING AWARENESS, IT TOOLS, URBAN PLANNING

Soil functions addressed (STS) | ECOSYSTEM GROUPS ADDRESSED (MAES)

☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)
☒ CARBON STORAGE (INCL. CLIMATE REGULATION)
☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)
☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)
☐ NUTRIENT CYCLING
☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)
☒ SOIL RELATED CULTURAL SERVICES (INCL. CULTURAL HERITAGE)

☐ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
☐ FOREST ECOSYSTEMS
☐ FRESHWATER ECOSYSTEMS
☐ MARINE ECOSYSTEMS
☒ URBAN ECOSYSTEMS

PROJECT OUTPUTS

THE PROJECT PROVIDED THE FOLLOWING CORE OUTPUTS:

•"SOIL MANAGER SUITE" INVOLVES IT TOOLS READY FOR USE WITHIN URBAN PLANNING PROVIDING A DESKTOP TOOL FOR END-USER PC COMPUTER APPLICATION AND A GIS WEB PLANNING TOOL FOR

EVALUATION OF SOILS FOR PLANNING PURPOSES.
•"MUNICIPAL SOIL MANAGER" IS A HANDBOOK FOR MUNICIPAL DECISION MAKERS GIVING PRACTICAL ADVICE HOW TO IMPLEMENT A PERMANENT MANAGEMENT STRUCTURE FOR SOIL PROTECTION WITHIN URBAN PLANNING.
•THE "PILOT ACTION CASE STUDY BOOK" ILLUSTRATES THE SUCCESSFUL IMPLEMENTATION AND THE BENEFITS OF THE DEVELOPED IT TOOLS ON REAL CASES.
•A "COMMUNICATION PACKAGE" IS A COMPILATION OF SOIL CONSUMPTION SCENARIOS, EVALUATION OF COMPENSATION MEASURES AND RESULTS FROM STAKEHOLDER WORKSHOPS INCLUDING A FILM ABOUT THE CONSEQUENCES OF SOIL CONSUMPTION.

Information on the regional variability and updated maps of soil organic carbon, soil pH, clay, nutrient availability, etc. across Europe

MORE INFORMATION

HTTP://WWW.UMWELTBUNDESAMT.AT/EN_URBANSMS

Indicate contact person(s) name, phone, email, post address:
boden@umweltbundesamt.at

PROJECT DATA

PROJECT NAME AND DURATION	PROJECT TYPE	CONTEXT	INTENDED USERS
ENVASSO	research project	*EU level*	*scientific*

Environmental Assessment of Soil for Monitoring

Countries covered by the project: EU

Start date: *22/12/2005* **End date:** *21/03/2008*

PROJECT SUMMARY

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 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.

PROJECT KEYWORDS

INDICATOR, MONITORING, SOIL THREATS

Soil functions addressed (STS)

- ☒ PROVISION OF GOODS (BIOMASS, FUEL, PHARMACEUTICALS, CONSTRUCTION MATERIALS)
- ☒ CARBON STORAGE (INCL. CLIMATE REGULATION)
- ☒ WATER PURIFICATION (AND SOIL CONTAMINANT REDUCTION)
- ☒ WATER FLOWS REGULATION (INCL. SEDIMENT PRODUCTION)
- ☒ NUTRIENT CYCLING
- ☒ SUPPORT FOR BIODIVERSITY (INCL. GENETIC RESOURCES)
- ☒ SOIL RELATED CULTURAL SERVICES (INCL.

ECOSYSTEM GROUPS ADDRESSED (MAES)

- ☒ AGROECOSYSTEMS (CROPLAND, GRASSLAND)
- ☐ FOREST ECOSYSTEMS
- ☐ FRESHWATER ECOSYSTEMS
- ☐ MARINE ECOSYSTEMS
- ☒ URBAN ECOSYSTEMS

CULTURAL HERITAGE)

PROJECT OUTPUTS

THE ENVASSO PROJECT HAS DEVELOPED A FRAMEWORK FOR MONITORING EUROPEAN SOILS. 27 INDICATORS WERE SELECTED FOR EROSION, ORGANIC MATTER DECLINE, CONTAMINATION, COMPACTION, SALINISATION, DECLINE IN BIODIVERSITY, SOIL SEALING, LANDSLIDES AND DESERTIFICATION. A MONITORING NETWORK WITH A DENSITY OF 1 SITE PER 300 KM2 COVERS MOST SOIL TYPE AND LAND USE COMBINATIONS. 20 INDICATORS WERE QUALIFIED FOR IMPLEMENTATION, COVERING SOIL EROSION BY WATER, DECLINE IN SOIL ORGANIC MATTER, SOIL CONTAMINATION, SOIL SEALING, COMPACTION, SALINISATION AND DESERTIFICATION.

The existing sites density was sufficient for continental soil monitoring over much of the European Union soil and the number of required new sites was relatively limited.

The majority of threats to soil resources were successfully monitored using the existing methodologies; however, current approaches proved inadequate for the assessment of carbon stocks in peat soils, wind erosion and tillage erosion.

The manual developed as part of ENVASSO was evaluated as being a valuable reference for future soil monitoring practices.

MORE INFORMATION

HTTP://CORDIS.EUROPA.EU/DOCS/PUBLICATIONS/1224/122436661-6_EN.PDF

HUBER, S, PROKOP, G., ARROUAYS, D., BANKO, G., BISPO, A., JONES, RJA., KIBBLEWHITE, MG., LEXER, W, MÖLLER, A., RICKSON, RJ., SHISHKOV, T., STEPHENS, M., TOTH, G., VAN DEN AKKER, JJH, VARALLYAY, G, VERHEIJEN, FGA AMD JONES, AR (EDS) (2008) ENVIRONMENTAL ASSESSMENT OF SOIL FOR MONITORING: VOLUME I INDICATORS AND CRITERIA. EUR 23490 EN/1 OFFICE FOR THE OFFICIAL PUBLICATIONS OF THE EUROPEAN COMMUNITIES, LUXEMBOURG, 339 PP. DOI 10.2788/93515

ARROUAYS D, MORVAN, X, SABY, NPA, LE BAS, C, BELLAMY, PH, BERENYI UVEGES, J, FREUDENSCHUß, A, JONES, AR, JONES, RJA, KIBBLEWHITE, MG, SIMOTA, C, VERDOOT, A, VERHEIJEN, FGA (EDS) (2008) ENVIRONMENTAL ASSESSMENT OF SOIL FOR MONITORING. VOLUME IIA INVENTORY AND MONITORING. EUR 23490 EN/2A OFFICE OF THE OFFICIAL PUBLICATIONS OF THE EUROPEAN COMMUNITIES, LUXEMBOURG, 88PP DOI 10.2788/93524

BARITZ, R, EBERHARDT, E, VAN LIEDEKERKE, MH, PANAGOS, P (EDS) (2008). ENVIRONMENTAL ASSESSMENT OF SOIL FOR MONITORING: VOLUME III DATABASE DESIGN AND SELECTION. EUR 23490 EN/3 OFFICE FOR THE OFFICIAL PUBLICATIONS OF THE EUROPEAN COMMUNITIES, LUXEMBOURG, 125 PP. DOI 10.2788/93697.

KIBBLEWHITE, MG, JONES, RGA, MONTARANELLA, L, BARITZ, R., HUBER, S., ARROUAYS, D., MICHELI, E. AND STEPHENS, M. (EDS) (2008) ENVIRONMENTAL ASSESSMENT OF SOIL FOR MONITORING: VOLUME VI SOIL MONITORING SYSTEM FOR EUROPE. EUR 23490 EN/6 OFFICE FOR THE OFFICIAL PUBLICATIONS OF THE EUROPEAN COMMUNITIES, LUXEMBOURG, 72 PP

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