Soils for Europe

SOLO

Synthesis typology of drivers of soil Health across land-use type and the European Union

Deliverable 3.2

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1 Introduction

Soil health in Europe is at a critical stage, with an estimated 60–70% of soils considered degraded (ESDAC, 2024). To achieve the goal of ensuring all soil ecosystems within the European Union (EU) are in a healthy state, the European Commission (EC) launched the EU Soil Mission, “A Soil Deal for Europe,” in September 2021 (Panagos et al., 2022). In addition, the EC proposed the Soil Monitoring Law, which establishes soil health targets up to 2050 and introduces a comprehensive system for soil monitoring and assessment ("Soil Monitoring Law," 2025). To achieve healthy soil, the soil mission focuses on research and innovations by funding research projects with partners in the EU and beyond to work together towards the mission objectives. Soils for Europe (SOLO) plans to identify current knowledge gaps, drivers, bottlenecks, and novel research and innovation approaches to be considered in the European Soil Mission research and innovation roadmap. The project aims to create a knowledge hub for soil health research and innovation that will last beyond the project’s lifespan by establishing strategic partnerships and implementing a participatory and transparent process. The purpose of Work Package 3 (WP3) in the SOLO project is to investigate the drivers of future changes in soil and land management, with the aim of identifying and understanding the emerging opportunities and challenges related to soil health. To help govern the work of WP3, certain milestones, workshops and deliverables are put in place. The task includes six milestones and two deliverables. The first deliverable, Deliverable 3, provides a typology of drivers that impact the future use and management of soil and land in the EU. In this second and final Deliverable 3.2, we provide a final report on the synthesis of the identified drivers of soil health across land-use types and the European Union.

Soil and land-use, intensity of their use, and management practices strongly influence soil condition and the ecosystem services it provides. To analyse soil health dynamics from a systems perspective, it is essential to understand the drivers behind land use and management decisions. For this purpose, the DPSIR framework was adapted to the European Union (EU) soil context and applied to identify drivers affecting soil health. A scoping review of the literature was carried out following the PRISMA protocol, structured into four categories based on land use types: urban and industrial, agricultural, forest, and natural areas. The drivers identified across these land uses were refined and standardised through in-person and online workshops. This metadata set compiles the list of drivers organised by EU soil mission objectives, land use type, and geographic location. The review forms part of the SOLO (Soils for Europe) project, funded under the EU Horizon Europe program, and the dataset will support collaborative knowledge-building platforms (think tanks) aligned with the soil mission objectives.

The work process for WP3 is set by the protocol developed as part of the milestone M1 (available as Appendix 1), completed in June 2023. An extensive meta-analysis following the established protocol was carried out. Deliverable 3.1 (see Appendix 2) establishes the typology of drivers, where they are located, and which soli health objectives they are impacting. Based on that output, this deliverable streamlines the typology of drivers with a synthesis of their association to land-use, location, and soil health, and establishes their influences on changes in the use, intensity and management of soil and land. The results of the outcomes from this analysis feed into the other work packages to support the development of the co-creation and knowledge development platforms for the EU soil mission objectives (i.e., Think Tanks, WP2). Apart from the use in the think-tanks of the SOLO project (WP2) for R&I roadmap development, the output of this result also corroborates with WP4 by helping with validating the soil week topics across the partners, as well as supporting the prioritisation and validation of the regional nodes activities.

Identifying the drivers of soil health is built upon a comprehensive analytical framework, which recognises drivers, pressures, state, impact, and response measures (DPSIR) as fundamental components of soil health. A meta-analysis was conducted to identify the drivers, which were divided into four parts based on different land-use (urban and industrial, agriculture, forest, and nature), which also corresponds to the four task leaders of WP3. The meta-analysis was conducted in accordance with the PRISMA protocol (Page et al., 2021). More than 40000 references have been scanned to filter out 451 relevant studies and to compile a list of drivers for soil and land-use changes in the EU (see Appendix 2). The identified drivers across all land uses have been adjusted and standardised in in-person and online workshops. The set list of drivers is being used to filter the metadata. The output of WP3 is directly of great benefit for stakeholders, policymakers, researchers, and scientists working towards ensuring the future of healthy soils in Europe or in general. Therefore, other forms of publications, opinion, conference or peer-reviewed papers, are also written and distributed to communicate the WP3 results.

2 Methodology

Driving force analysis was built upon the DPSIR framework, which recognised drivers, pressures, states, impacts, and responses as fundamental components of soil health (detailed in Section 2.1). The task was subdivided across four land-use types: agriculture, forestry, natural areas, and urban and industrial areas. The work of the different task groups was led and coordinated by the WP3 leader, Leibniz Centre for Agricultural Landscape Research (ZALF). To achieve the aim of this study, which is to investigate the drivers of future changes in soil and land management, with the aim of identifying and understanding the emerging opportunities and challenges related to soil health, the following three steps were taken:

- **Step 1 –** Typology of the drivers for future changes in soil and land-use management
- **Step 2 -** Drivers' interactions and impacts on soil and land-use management over time
- **Step 3** - Analysis of drivers and their dynamics for future changes in soil and land-use management

Section 2.2 elaborates on the protocol adopted to carry out the steps. The protocol was developed and outlined in detail as a milestone M1, which was communicated among SOLO partners in June 2023. The milestone document is available as Appendix I. The data analysis protocol, as well as the sorted data (for drivers), have also been communicated as a journal article by Chowdhury et al. (2024), which is available as Appendix II.

2.1 Analytical framework - DPSIR

The DPSIR framework, comprising Drivers, Pressures, States, Impacts, and Responses, is a widely applied method for analysing how human activities affect environmental systems, especially soil health (Chowdhury et al., 2025). It has been integrated into several EU initiatives and adapted for the SOLO project (Figure 1) to explore future soil health challenges across Europe. In this model, the state represents soil health objectives, including eight mission objectives and soil biodiversity (referring to the Think tanks established as per WP2). Impacts refer to effects on soil ecosystem services, while pressures involve changes in land-use and soil management. Responses are strategies aimed at maintaining or improving soil health, ideally by addressing the root causes, Drivers that caused the changes to take place.

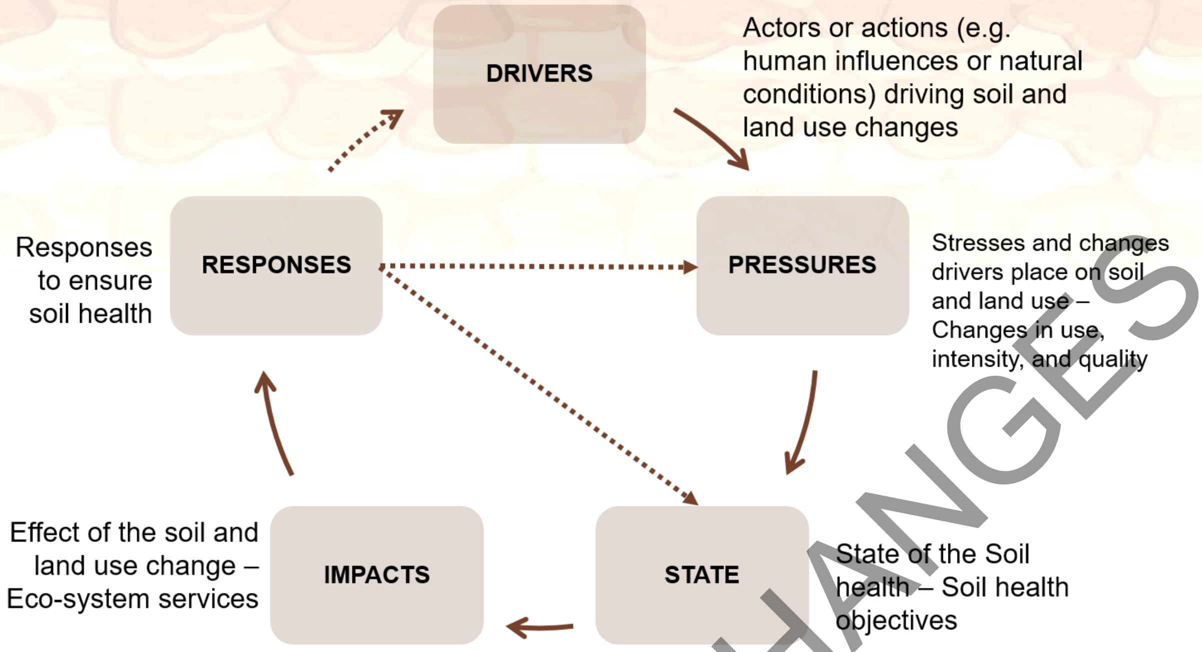

Figure 1: DPSIR Framework schematic for future soil and land use management for soil health (from Chowdhury et al. (2024))

2.2 Work protocol for WP3

A meta-analysis protocol (M1) was developed to guide the methodological steps needed to create a typology of soil health drivers. These drivers were chosen based on their potential to influence future changes in three key areas: land-use, land management, and the quality of management. Changes in land-use refer to shifts in how land is utilised, such as its type (e.g., more uniform or diverse use) or intensity (e.g., increased or reduced exploitation). Changes in management involve modifications in how soil and land are handled, including new regulations or practices. Lastly, changes in management quality reflect how effectively land-use integrates environmental, social, and economic functions. The protocol is available in the appendix for a more detailed Figure 2 presents a graphical summary of the meta-analysis strategy, which is briefly described in the following sections. For a more detailed description, please see appendix 1 and 2.

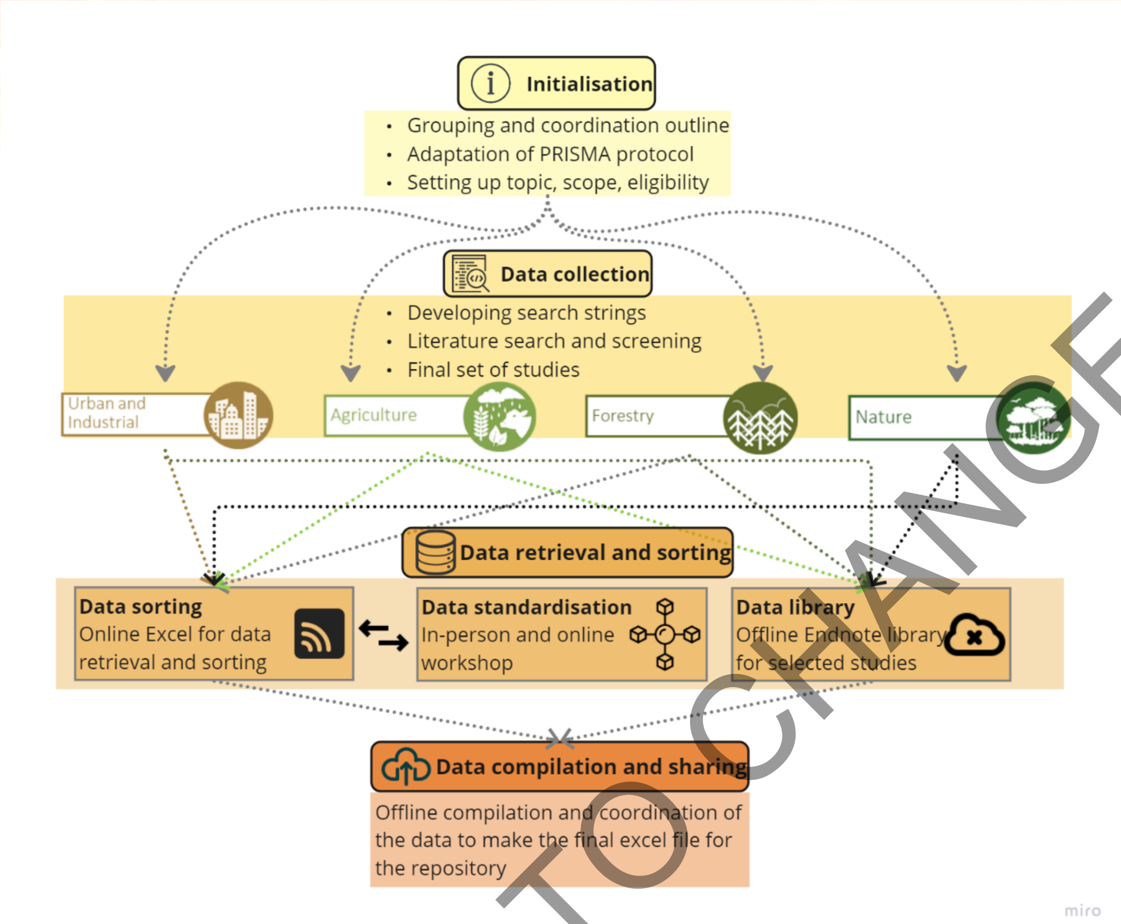

Figure 2: Meta-analysis strategy for WP3 (from Chowdhury et al. (2024))

2.2.1 Data collection

To establish the typology of drivers, the initial inventory of studies on drivers of changes for different land-uses was created by analysing the existing literature on the topic. PRISMA protocol was used as a guide and synchronise the meta-analysis process (see Appendix I). The data collection took place in parallel for four land-uses, so certain standards regarding the timeline, the search engine, language and location have been set (Table 1) prior to the review process. The review was largely limited to the peer-reviewed published literature available on Scopus, but there were scopes outlined to enrich the search with grey literature.

Table 1: Details of data collection for the meta-analysis

PUBLICATION TYPE:	**PEER-REVIEW, GREY LITERATURE (POLICY REPORTS, EU PUBLICATIONS, ETC.)**
TIME LINE	2010-2023 and predictions up to 2100
SEARCH ENGINES	Scopus
KEY WORDS	Select general and specific keywords related to land-use types and drivers.
LANGUAGE	English and local language (regional specific)
SPATIAL	Regional to European level

2.2.2 Data sorting

The structure for data sorting to take place after the data collection is presented in Table 2. The drivers' description and the associated references were collected in a separate table (see appendix). Table 2 provides the format for more detailed information regarding the identified drivers. The first two columns of the table are for the drivers. The first column refers to the category, and the second to specific drivers. The third column is for reference to the associated citation. Columns four to six are grouped under the likelihood of affecting different changes in soil, land-use, and management quality (i.e., pressure). Columns seven to nine are grouped under the ubiquity or specific setting (context) in which it is likely to be relevant. Column seven contains the information on location, which is usually limited to the NUTS0 level within EU33. Still, if not possible, other location-based information, such as regional or climatic zone, is also included. Column eight contains land cover per environmental zone, which follows the Corrine land cover classification (Kosztra et al., 2019) for the four types of land-uses. The final column contains the relevant soil health objective (s) that the driver(s) are associated with. One of the rows is filled as an example.

Table 2: Format for updated list of drivers for the future with brief exploration

List of drivers for 'Insert land-use'		Citation	Likely to affect			Ubiquity or a specific setting in which it is likely to be relevant		
Categories	Individual drivers		Land-use change	Land-use intensity	Management quality	Location	Land cover per Environmental zone	Relevant soil health objectives
Technology and Management	Climate change - Shift in precipitation, temperature, and wind patterns	47	Same	Possibly changed	Worsened	Spain	Permanent crops - Vineyards	Soil erosion
	Driver 2							
	Driver n							

2.2.3 Data standardisation

The data was collected and sorted by four task groups separately. Since the list of drivers was not a set list, instead a guide was provided for sorting, it was predicted that there would be a need to standardise the drivers in terms of scope and language across all land-uses. To facilitate this process, workshops were planned and designed. The drivers were further regrouped and streamlined by the work package leader for better communication. The language for the other likely to affect columns was also further streamlined.

2.2.4 Data communication

The communication of the data was designed to take place periodically across the SOLO partners and the wider audience. The initial set of drivers, grouped across soil health objectives, was to be communicated with the WP2 think tanks to collect their input. The country-specific drivers, as well as the associated soil health objectives and land uses are also separately generated and communicated to WP4 regional nodes members to support their workshops with stakeholders. The results were periodically communicated to all project partners and stakeholders attending the general meetings. General communication with the wider audience has been and will take place in the form of scientific journal publications and conference proceedings, as well as public reports. Chapter 5 details the communication of the data in more detail.

3 Meta-analysis in brief

The meta-analysis protocol, as well as the relative work protocol of WP3, was finalised as Milestone 1, which was detailed at a later stage to accommodate the synthesis. The following sections elaborate on the collection, sorting, standardisation and communication of the metadata according to the protocol.

Data curation following the PRISMA protocol was conducted for four land-use categories for four land-uses separately. The PRISMA protocol was followed for the data collection and sorting, and the process is detailed further in Deliverable 3.1 and in the data paper available in the appendix. Initially, search strings were developed and used to retrieve literature from Scopus. Preliminary filtering based on timeline, language, and duplicate removal eliminated a significant portion of the results. Subsequently, the four task groups—each focused on a specific land use—adopted slightly different approaches. Most groups applied an additional relevance filter by reviewing titles and abstracts. The variation in workflow depended on collaboration among partners within each task. For nature and agriculture, literature tracking was first done in offline Excel sheets and later updated online. In contrast, urban and forest groups worked directly in the online Excel file. In total, 53,203 records were screened across the four land uses, resulting in a final set of 447 studies.

The first stage of data filtering focuses on identifying the drivers, case study location and relevance to soil health objectives. With the data being collected and compiled by four land-uses (i.e task groups) separately, it was deemed necessary to standardise the language of the drivers as only references were provided, rather than a concrete list of drivers of future soil or land use or management could be found in the literature. The existing contents up to Oct 2023 of the online Excel file on the list of drivers of all land uses were grouped and standardised to provide a harmonious list of drivers that would be consistent for the rest of the meta-analysis process. The data standardisation took place in two workshops, one in-person workshop and another online workshop. The drivers were then linked to the associated soil health objectives and locations. These initial outcomes were shared with the SOLO consortium in December 2023 (Barcelona), and a more finalised version was presented during the consortium meeting in April 2024 (Wageningen). The first set of drivers formed the basis for the typology of drivers, and they were communicated and detailed in Deliverable 3.1.

The second stage of data sorting focuses on the changes in the use, intensity, and management (i.e. pressures) in the soil and land-use associated with the drivers. To start with the process, the typology of drivers is further streamlined and updated in Milestone 11. The drivers are then associated with different main types and subtypes under the main land-use following the Corine Land Cover (CLC) classifications (Kosztra et al., 2019). This was done by the WP§ leader with the data already collected on the online Excel file used for data collection. As well as sorting the rest of the data, the drivers are also analysed for their dynamics. Their association with different locations, land-use, and soil health objectives are compared to provide a synthesised outlook on the impact of the drivers.

4 Drivers – Actors or actions driving soil and land-use change

The typology of drivers is a standardised set of all the drivers, identified across all the land-uses that could impact the soil and land-use change and management. In total, 451 studies were sorted by meta-analysis across four land-uses: agriculture (164), forestry (44), natural areas (165), and urban and industrial areas (79) (one study was common between nature and agriculture). The full text of the studies was explored to identify different drivers and associated information (see Table 2). The drivers are further grouped in six categories: technology and management, nature and environment, demography, policy and institutional arrangements, socio-cultural contexts, and economy. The categories of drivers and their association with different land-use and soil health objectives, and distribution across the EU, are further explored in the following sections. The following figures summarise the data implications across the EU for different driver categories (Figure 3) and different soil health objectives (Figure 4).

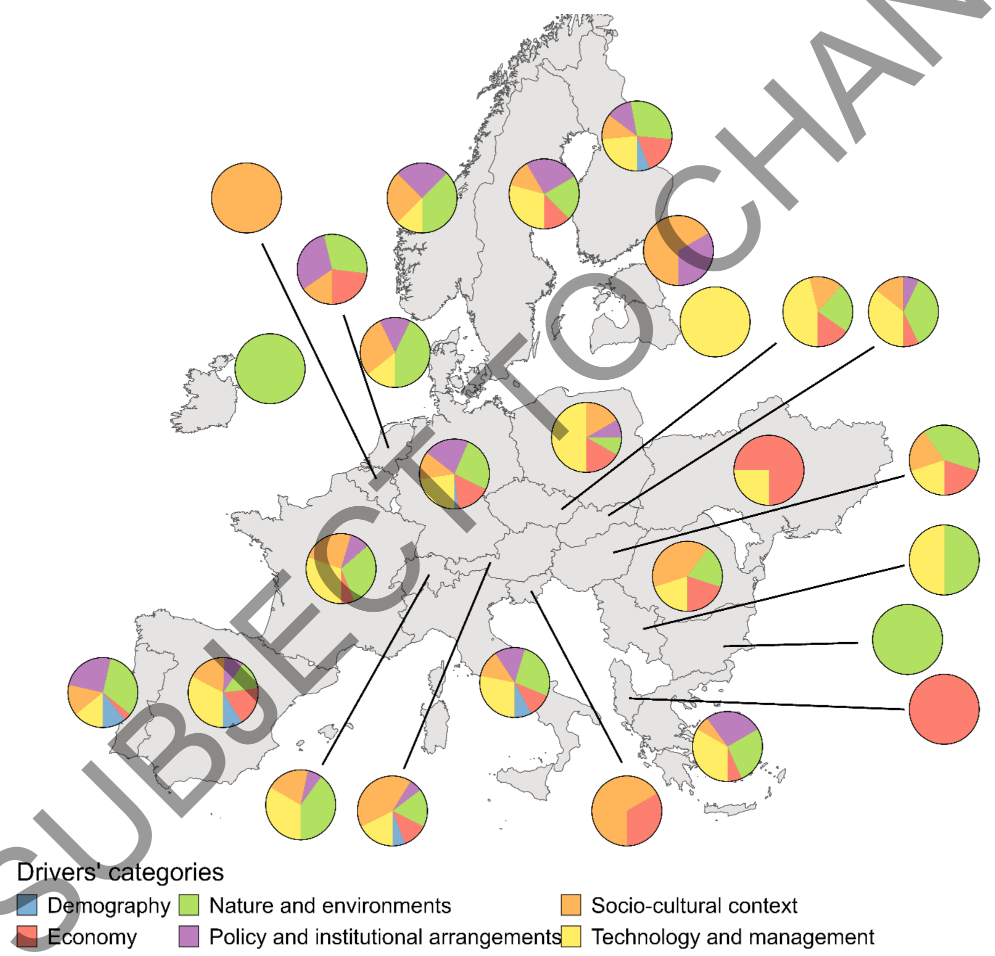

Figure 3: Distribution of different categories of drivers across the EU

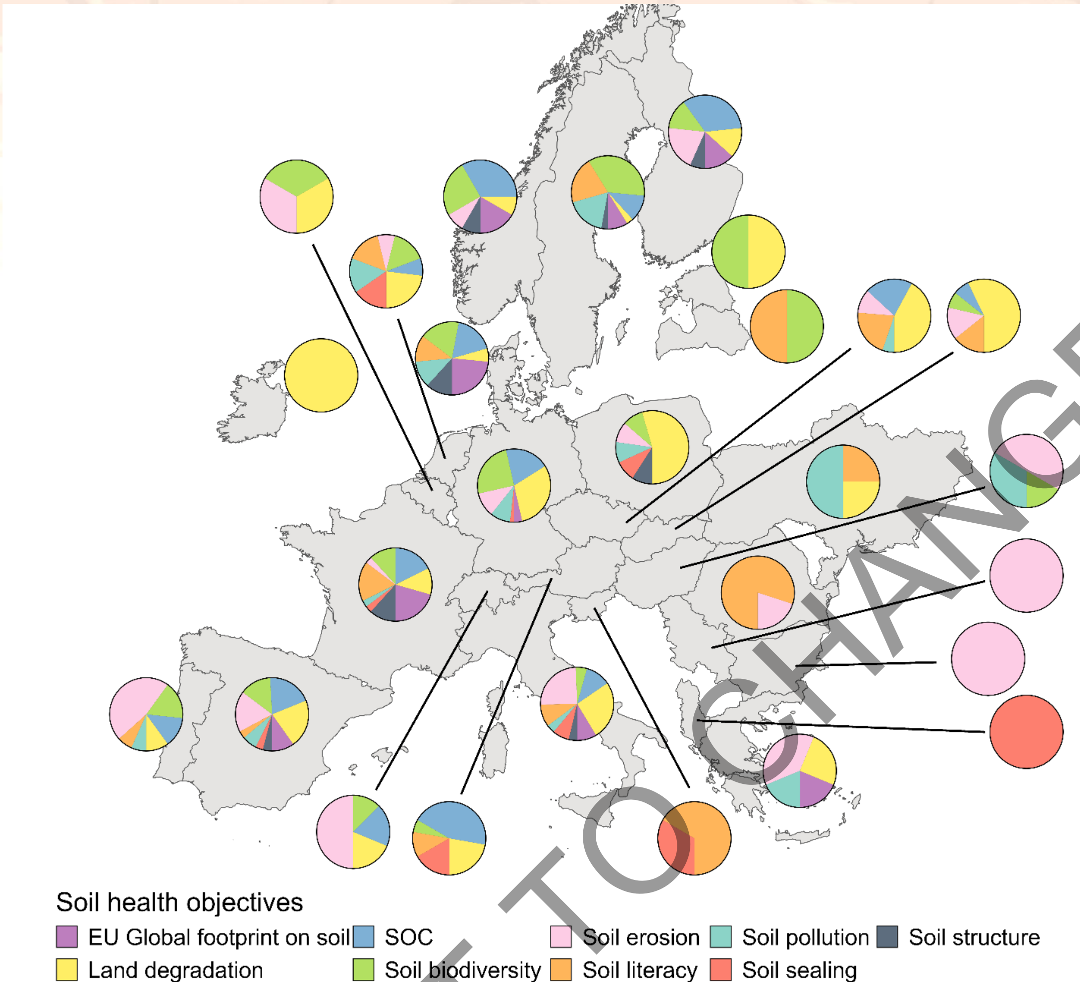

Figure 4: Distribution of different soil health objectives affected by the analysed drivers across the EU

4.1 Technology and Management

Table 3 presents the list of drivers related to technology and management. The drivers are then divided into generic and specific groups, with the specific drivers being associated with a generic driver. There are five generic drivers in the technology and management drivers category with sub-drivers grouped within the four themes: management and planning, soil amendments and machineries, waste and pollution, and water. The drivers are colour-coded, and the colours were used in the following sections.

Table 3: Technology and management drivers for soil health

Generic	Specific			
	Management and planning	**Soil amendments and machinery**	**Waste and pollution**	**Water**
Current land management practice	Current soil management practice during construction	Use of fertiliser Frequency and timing of machinery use Increased size of machinery	Current waste management practices Current management and regulations about contamination and contaminated sites Emerging novel pollutants (micro- or nano-plastics) Research and implementation of soil remediation techniques on contaminated sites	Increasing demand for water
Adoption of Nature-based solutions for climate change mitigation (Sustainable practices)	Adoption of digital platforms for soil health monitoring and information sharing	Advancement and adoption of precision agriculture technologies	Advancement of waste management practices	Advancement in the monitoring and management of water resources
Advances in tools and models for soil monitoring and land management	Advancement in artificial surfaces Advancement in remote and proximal sensing and imaging	Advancement and adoption of efficient fertiliser replacement and recovery technologies Promotion and acceptance of the use of organic fertiliser, treated sludge and wastewater	Advancement in monitoring and management of contaminated sites	
Recognition of the need for efficient spatial planning strategies across all land uses	Recognition of monetary benefits of ecosystem services in spatial planning Promotion and integration of green infrastructure in urban and industrial areas		Promotion and integration of improved soil sealing and stabilising strategies	
Recognition of the need and progress towards standardisation of soil health indicators	Promotion and integration of ecosystem services in spatial planning Promotion and integration of resilience building through spatial planning			

4.1.1 Distribution across land-use types

The bar chart in Figure 5 presents the distribution of the studies associated with different technologies and management drivers across the four land-uses. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to different technology and management drivers presented in Table 3. Agriculture is the most referenced, more than double that of the second most referenced, Forest, for technology and management, with all generic drivers being referenced with the Adoption of Nature-based solutions for climate change mitigation and Advances in tools and models for soil monitoring and land management being the prominent generic ones. Studies have not, however, linked the Adoption of Nature-based solutions for climate change mitigation to forest land-use, with most references to the generic driver, Current land management practice and its specific drivers. Nature is the land use that studies have least associated with drivers of this category.

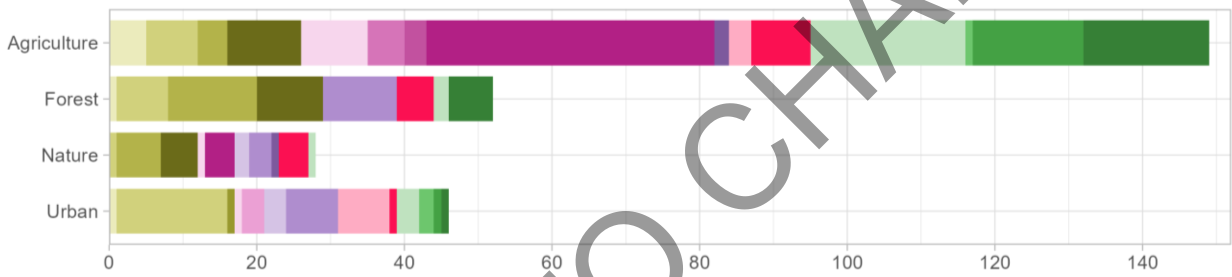

Figure 5: Technology and management drivers for soil health across four land-use types (The colour coding refers to different technology and management drivers presented in Table 3. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.1.2 Distribution across the EU

The bar chart in Figure 6 presents the distribution of the studies associated with different technology and management drivers across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to different technology and management drivers presented in Table 3. Drivers in this category are linked by the studies to be mostly influential everywhere, as well as in the EU, with Spain being the member state with the most associations. Current land management practices and the associated specific drivers are identified the studies the most number of times to be influential in changes in the use and management of soil and land. Spain is linked to eight studies that suggest it is influenced by current land management practices, specifically those associated with waste and pollution (e.g., novel pollutants such as nano-plastics) and water. Advancements in tools and models for soil monitoring and land management, and the associated specific drivers, are the second most associated drivers in this category. Italy is explored by eight studies, with four associated with management and practices (e.g. remote and proximal sensing). Adoption of alternative measures, such as nature-based solutions and sustainable practices (e.g. cover crops, reduced tillage), is also widespread in the EU, with the Mediterranean region and the countries within being specifically associated by the studies. As well as the adoption of new technologies and management practices, recognition of the need and progress towards standardisation of soil health and its indicators and efficient spatial planning strategies are also identified by the studies to be influential in the region.

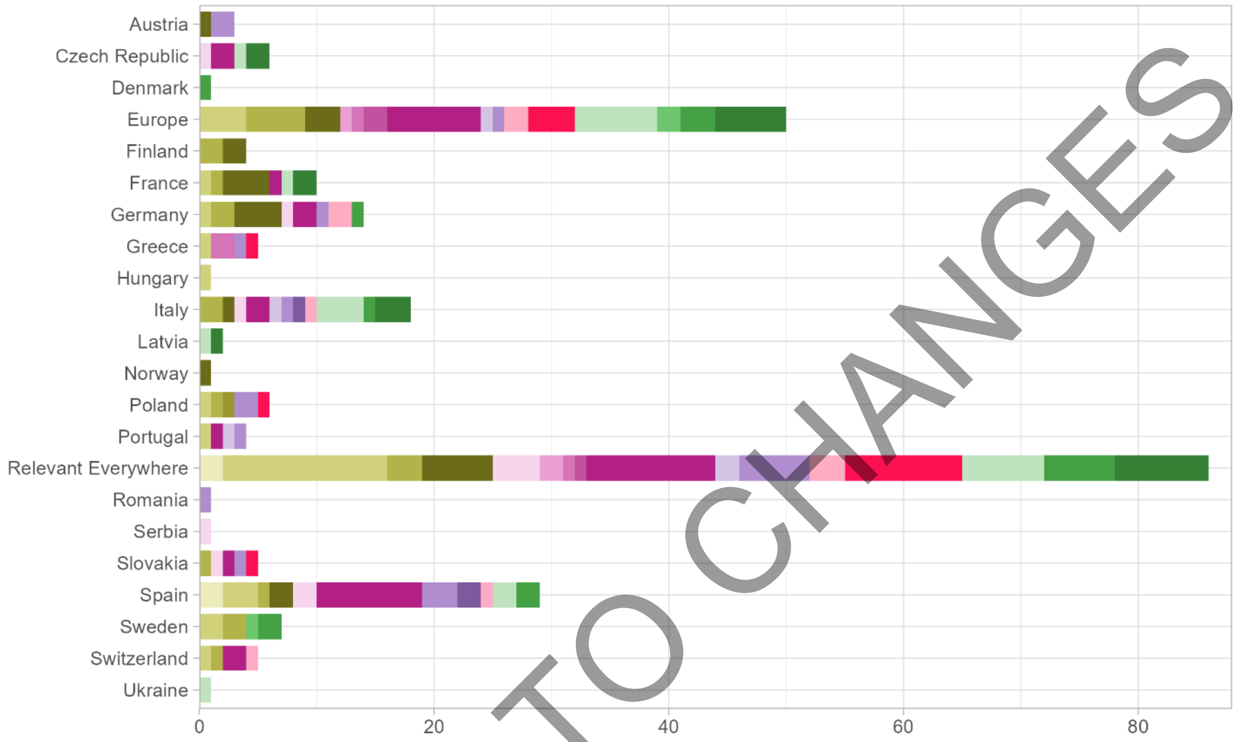

Figure 6: Technology and management drivers for soil health across the EU (The colour coding refers to different technology and management drivers presented in Table 3. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.1.3 Distribution across soil health objectives

The bar chart in Figure 7 presents the distribution of the studies associated with different technologies and management drivers across different soil health objectives. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to different technology and management drivers presented in Table 3. Technology and management drivers are more or less equally relevant to most soil health objectives, with the highest association to soil literacy, followed by soil pollution and land degradation. The least associated soil health objectives are soil sealing, followed by soil structure.

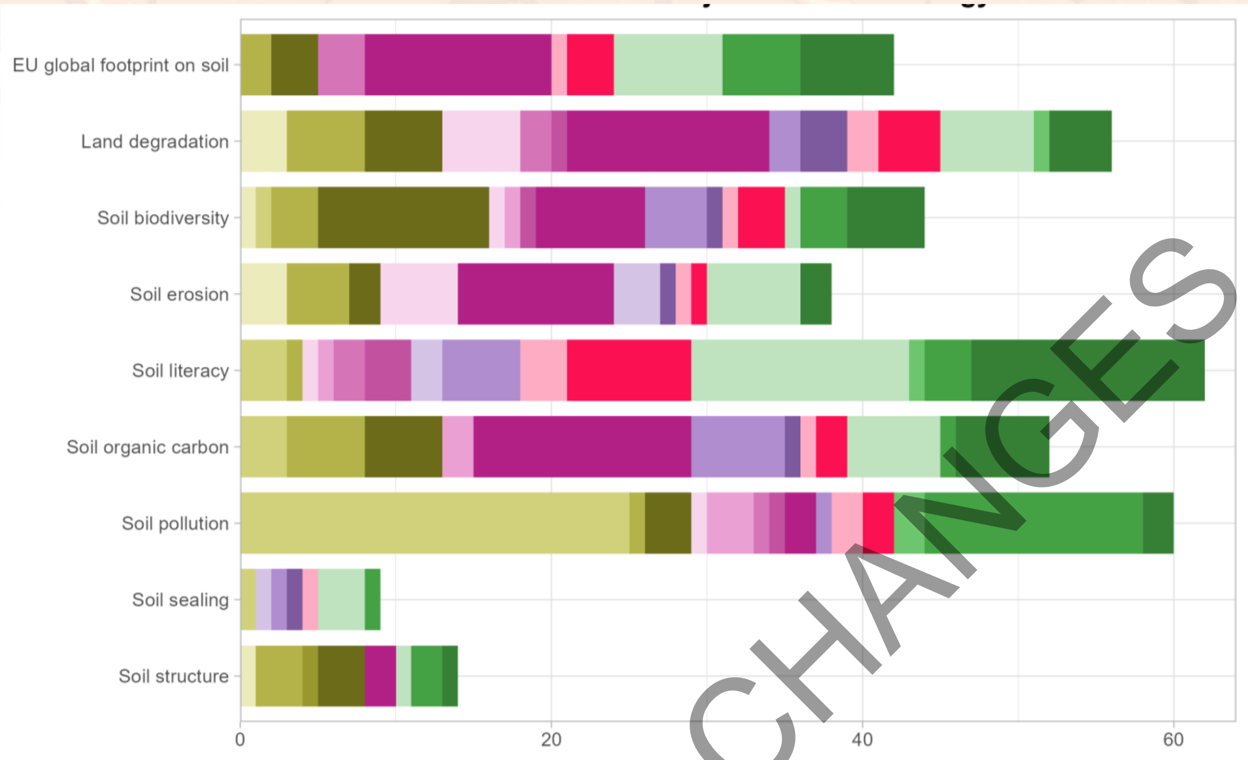

Figure 7: Technology and management drivers for soil health across soil health objectives (The colour coding refers to different technology and management drivers presented in Table 3. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.2 Nature and environments

The following Table 4 presents the list of drivers related to nature and environment. The drivers are then divided into generic and specific groups, with the specific drivers being associated with a generic driver. Climate change is the main generic driver in this category, with eight specific drivers, and to a large extent, the generic driver, Extreme weather, is associated with it. The drivers are colour-coded, and the colours were used in the following sections.

Table 4: Natural drivers for soil health

Generic		Specific
Climate change		Sea level rise
		Shift in precipitation, temperature, and wind patterns.
		Decreased precipitation
		Increased precipitation
		Increased temperature
		Prolongation of the growing season due to a warming climate
Extreme weather		
Invasive species		
Abiotic factors		

4.2.1 Distribution across land-use types

The bar chart in Figure 8 presents the distribution of the studies associated with different nature and environment drivers across the four land-uses. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding referring to different nature and environment drivers is presented in Table 4. Nature is the most referenced with all the drivers apart from the prolongation of the growing season, and invasive species. Agriculture is the second most referenced land use in this driver category, followed by forest and urban land uses.

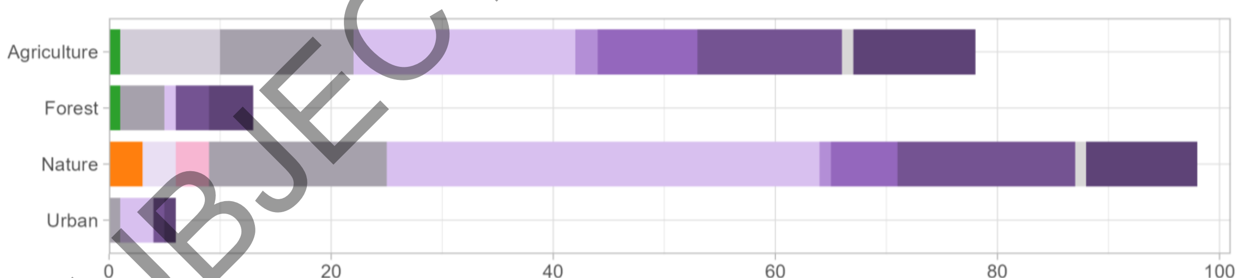

Figure 8: Natural drivers for soil health across land-use types (The colour coding refers to different nature and environment drivers presented in Table 4. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.2.2 Distribution across the EU

The bar chart in Figure 9 presents the distribution of the studies associated with different nature and environment drivers across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding referring to different nature and environment drivers is presented in Table 4. The primary natural category driver is climate change, along with its most significant characteristics as specific drivers. Shifts in weather patterns, such as precipitation, temperature, and wind, have been identified the most by the studies. This driver is expected to influence soil and land use change everywhere, with studies linking it to Europe and the Mediterranean region specifically. Countries in the Mediterranean region, Italy, Spain, Portugal, and Greece, are all individually linked to this driver in studies. Many studies have also linked shifts in weather patterns to Germany. Extreme weather events due to climate change are the second most identified natural driver, and studies have found this driver to be relevant everywhere, including many countries across the EU. Increased temperature is another driver, similarly linked by studies to be influential. Changes in precipitation, increased and decreased, are similarly spatially diverse, identified by a lesser number of studies. Prolongation of the growing season, however, is linked to the countries in the north, Sweden, Finland, and Norway. Sea level rise is the driver that is the least explored climate change phenomenon in studies in relation to soil and land use change and their impacts on soil health, with the Netherlands being the only member state individually linked. Abiotic factors (e.g. pH) are the second primary category of natural drivers that are linked to be influential everywhere, with a specific association to Germany. Invasive species are the final driver in this category to influence soil and land use change everywhere, as well as in Europe. Italy, Spain, France, and Germany are the most individually explored in this category.

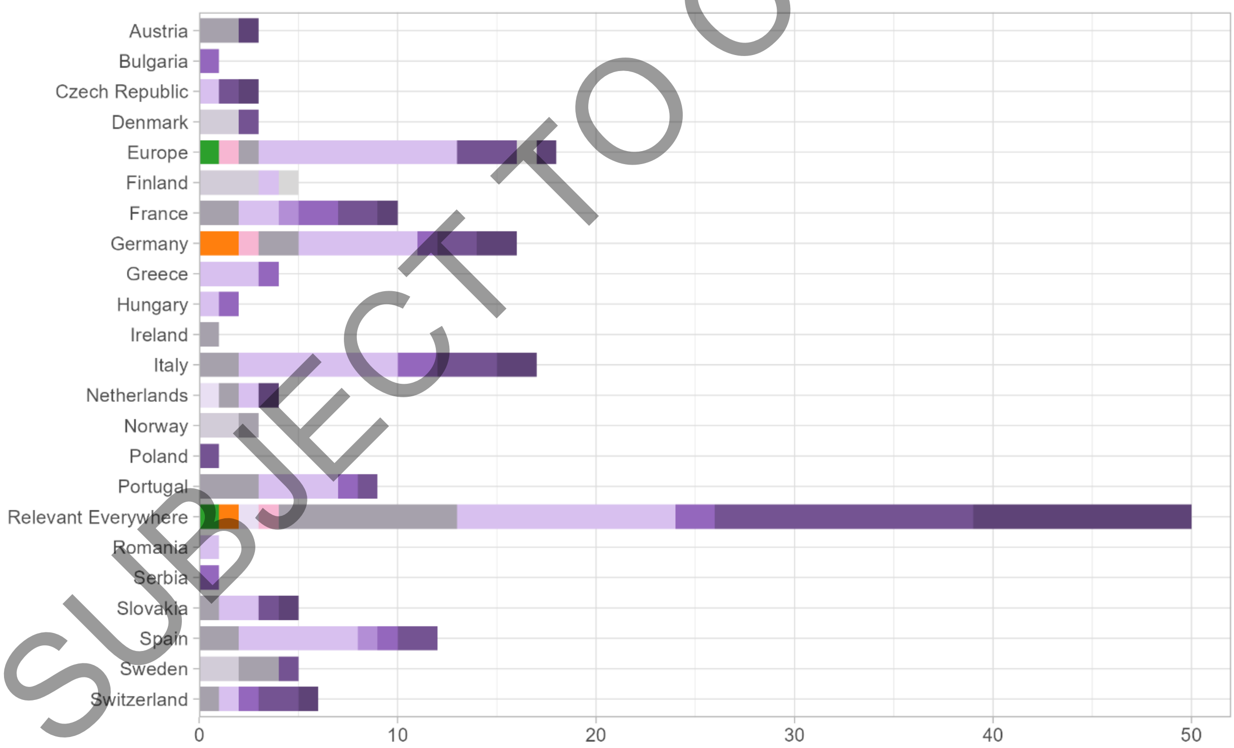

Figure 9: Natural drivers for soil health across the EU (The colour coding referencing different nature and environment drivers presented in Table 4. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.2.3 Distribution across soil health objectives

The bar chart in Figure 10 presents the distribution of the studies associated with different nature and environment drivers across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding referring to different nature and environment drivers is presented in Table 4. The highest association with nature and environment drivers among the soil health objectives is land degradation, followed by soil erosion and SOC. Invasive species are only associated with soil biodiversity. Soil structure and soil sealing are the soil health objectives that studies have not explored in association with the nature and environment drivers.

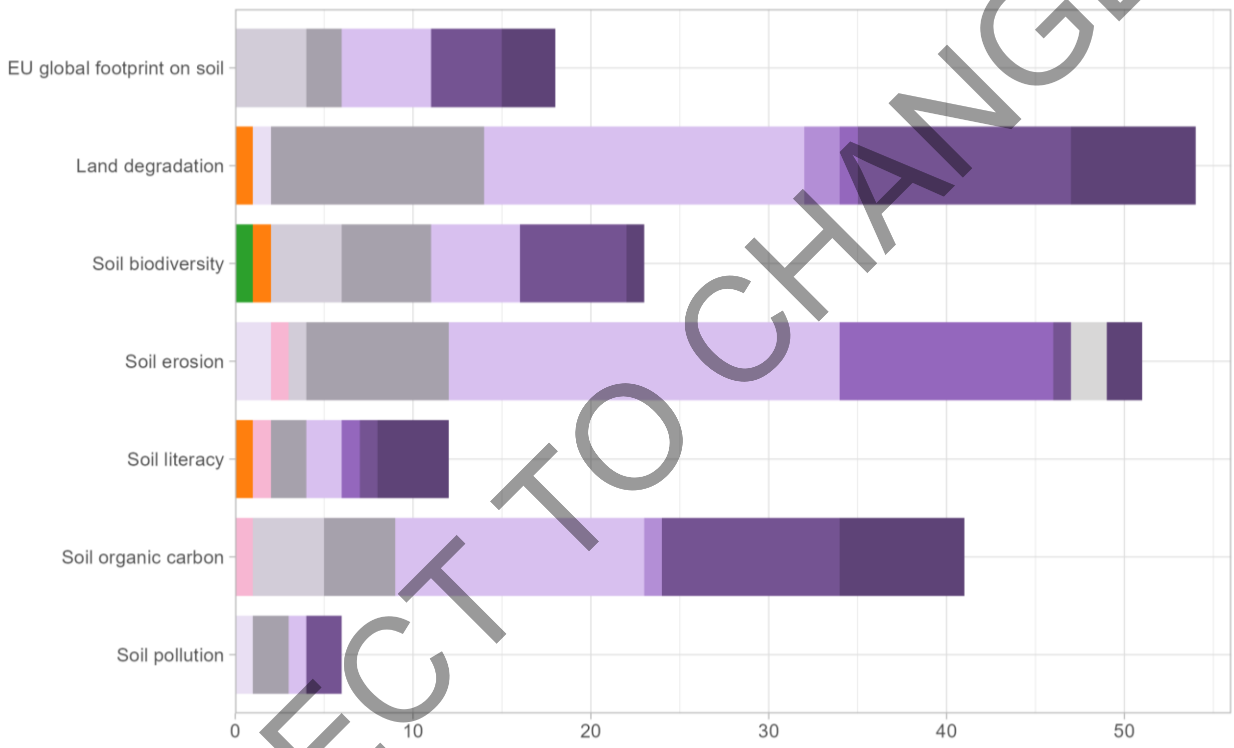

Figure 10: Natural drivers for soil health across Soil health objectives (The colour coding refers to different nature and environment drivers presented in Table 4. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.3 Demography

The following table 5 presents the list of drivers related to demography. The drivers are then divided into generic and specific groups, with the specific drivers being associated with a generic driver. There are four generic drivers and five specific drivers identified in this category. The first generic driver is Ageing, with two specific drivers, Decline in active labour in agriculture, and Changes in ownership and tenure. The second generic driver is migration, with three specific drivers associated: Declining rural population, Decreasing population density in rural areas, and Internal migration. The final two generic drivers are increasing population and household size and per-capita land consumption, with no specific drivers. The drivers are colour-coded, and the colours were used in the following sections.

Table 5: Demographic drivers for soil health

Generic	Specific
Aging	Decline in active labour in agriculture
	Changes in ownership and tenure ship
Migration	Declining rural population
	Decreasing population density in rural areas
	Internal migration
Increasing population	
Household size and per-capita land consumption	

4.3.1 Distribution across land-use types

The bar chart in Figure 11 presents the distribution of the studies associated with different demographic drivers across the four land uses. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to different demographic drivers presented in Table 5. The largest share of studies refers to agricultural land use and connects it with all demographic drivers except the household size and per–capita income, as the referencing studies link the driver to urban and industrial land use. Population increase and migration are the drivers identified as the drivers for influencing changes in the use and management of natural land uses.

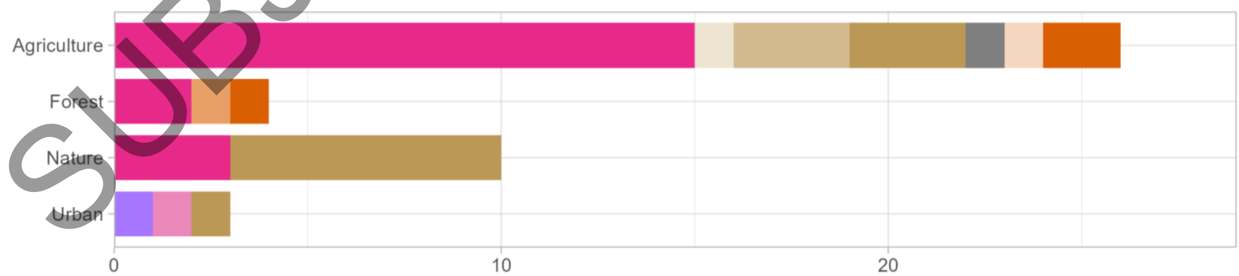

Figure 11: Demographic drivers for soil health across land-use types (The colour coding refers to different demographic drivers presented in Table 5. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.3.2 Distribution across the EU

The bar chart in Figure 12 presents the distribution of the studies associated with different demographic drivers across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to different demographic drivers presented in Table 5. The increasing population is the driver with the most associated studies in the demography category. While most of these studies assume this driver to be relevant everywhere, the Mediterranean region, specifically Italy, is highlighted by the studies as being impacted by the driver. Alternatively, countries in the Mediterranean region (Spain, Italy and Portugal) are also largely affected by migration and associated drivers, primarily by declining population in the rural areas. Ageing is another driver within this category, where studies have largely associated it with Spain. Spain is the country most identified by studies to be impacted by demographic drivers, followed by Italy and Portugal.

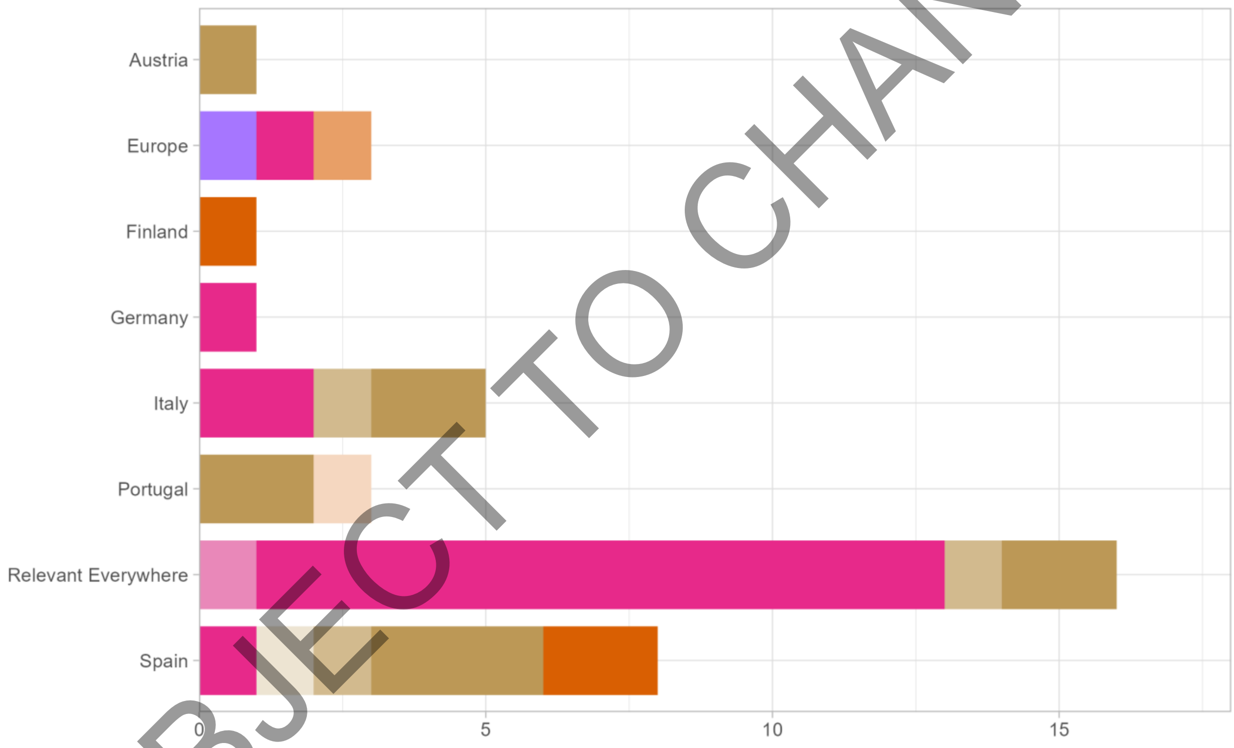

Figure 12: Demographic drivers for soil health across the EU (The colour coding refers to different demographic drivers presented in Table 5. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.3.3 Distribution across soil health objectives

The bar chart in Figure 13 presents the distribution of the studies associated with different demographic drivers across soil health objectives. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to different demographic drivers presented in Table 5. The most impacted soil health objective by the demographic drivers is land degradation, followed by soil pollution and SOC. Although a variety of different demographic drivers are linked to land degradation, soil biodiversity and the EU global footprint on soil are only connected to population increase. No study specifically connects soil literacy to demographic drivers. Soil pollution and SOC are associated with only two drivers, population increase and migration, with the former being dominant in soil pollution and the latter in SOC.

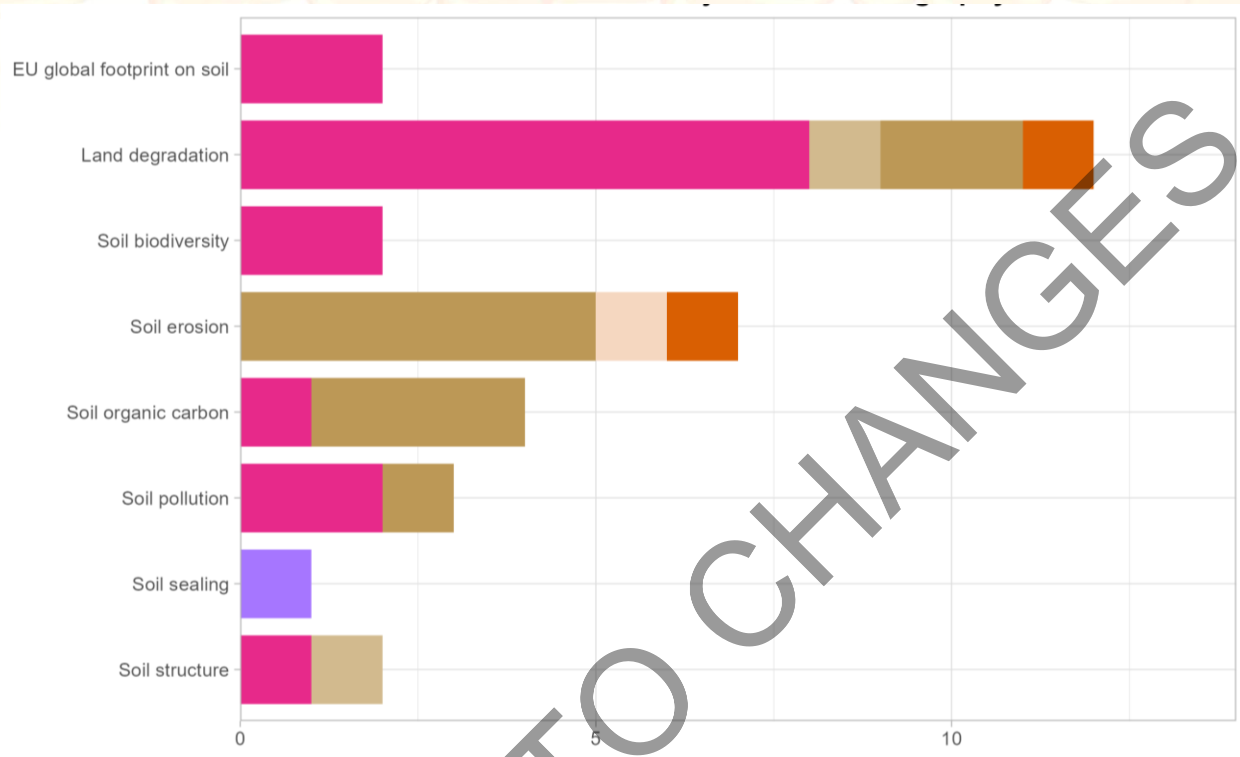

Figure 13: Demographic drivers for soil health across soil health objectives (The colour coding refers to different demographic drivers presented in Table 5. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.4 Policy and institutional arrangements

The following table 6 presents the list of drivers related to policy and institutional arrangements. The drivers are then divided into generic and specific groups, with the specific drivers being associated with a generic driver. There are ten generic drivers in this category, with six related laws and regulations, sustainable development, climate, waste and pollution, conservation, agriculture, and soil and land, and four others, combined effects of global, EU, national measures, research demands by EC, conflicts between regional and local policies, and unspecified laws. Regulations and strategies. To provide context for the numerous drivers identified in this category, the first six drivers are further dived in the following specific categories: drivers associated with laws and regulations are further grouped according to the six main topics they are associated with, Global - International strategies, agreements and conventions, EU - EU level strategies, agreements, conventions, laws and regulations, and National- National-level strategies, agreements, conventions, legislations and laws. The drivers are colour-coded, and the colours were used in the following sections.

Table 6: Policy and institutional arrangements drivers for soil health

Generic	Specific		
	Global - International strategies, agreements and conventions	**EU - EU level strategies, agreements, conventions, laws and regulations**	**National-National-level strategies, agreements, conventions, legislations and laws**
Laws or regulations regarding Sustainable development	SDG	European Green Deal (including circular economy action plan)	
		Renewable Energy Directive (EU) 2023/2413	
Laws or regulations regarding climate	COP26 Glasgow Climate Pact	European Climate Law 2021/1119	Renewable Energy Act (German: EEG)
		Industrial Emissions Directive	Stratégie Nationale Bas-Carbone 2020 (France)
Laws or regulations regarding waste and pollution	United Nations Environmental Program, Society of Environmental Toxicology and Chemistry (SETAC)	Zero pollution action plan	
		Sewage sludge directive	
		Urban wastewater directive	
		Water Framework Directive	
		Strategic Approach to Pharmaceuticals in the Environment COM/2019/128 final	
Laws or regulations regarding conservation		Biodiversity strategy for 2030	Spanish Forest Plan
		Birds Directive 2009/147/EC	
		Habitats Directive 92/43/EEC	
		Nature Restoration Law 2022/0195	
Laws or regulations regarding agriculture		Common Market Organisation regulation for wine production (CE 555/2008)	German Fertiliser Ordinance
		Nitrates Directive 91/676/EEC	
		Common Agricultural Policy (CAP)	
		Common Agricultural Policy (CAP) - Pillar 1 support payments and trade liberalisation	
		Common Agricultural Policy (CAP) - Pillar 2 Natura 2000	
Laws or regulations regarding soil and land	UNCCD's Land Degradation Neutrality Programme	EU soil strategy	Soil Support Programme and LKV (Switzerland)
		Proposed EU soil monitoring law 2023/0232	
		Reform of the Landfill directive	
		Horizon Europe soil mission - funding for research	
Combined effect of Global, EU, and National measures			
Research demands by EC			
Conflicts between regional and local policies			
Unspecified laws. Regulations and strategies			

4.4.1 Distribution across land-use type

The bar chart in Figure 14 presents the distribution of the studies associated with different policy and institutional arrangements drivers across the four land-uses. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different policy and institutional arrangements drivers presented in Table 6. The largest share of studies refers to agricultural land use and connects it with most policy and institutional arrangements drivers. Nature is the second most referenced, followed by urban, with forest being the least referenced.

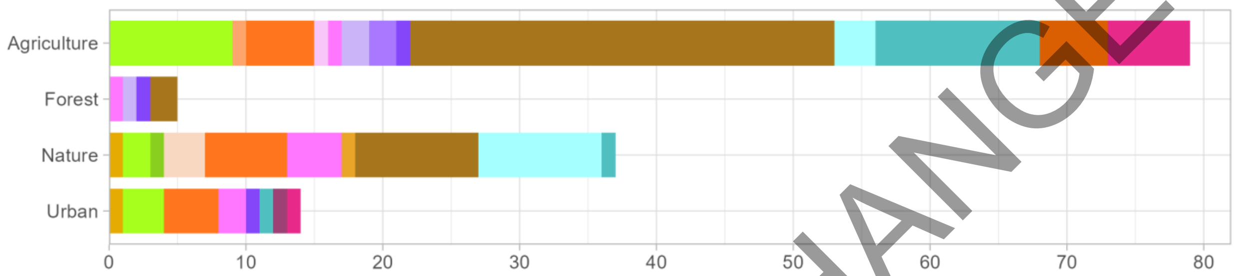

Figure 14: Policy and institutional drivers for soil health across land-use types (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 6. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.4.2 Distribution across the EU

The bar chart in Figure 15 presents the distribution of the studies associated with different policy and institutional arrangements drivers across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different policy and institutional arrangements drivers presented in Table 6. As the study is focused on the EU region, a lot of the policies that have been identified are regional strategies and directives, which are largely associated with impacting the entire region, with some highlighted to have a wider impact. EU-level laws and regulations regarding agriculture (e.g., the Common Agricultural Policy (CAP)) are identified as having the highest influence on changes in soil and land use and management and associated soil health. The Nitrates Directive is another regulation highlighted by several studies in this group. Studies have connected the driver with the EU and member states across the EU. Similarly, laws and regulations regarding soil and land in the EU (e.g. EU soil strategy, the Soil monitoring law) are expected to have an impact on soil health across the region. UNCCD's land degradation neutrality programme is identified as a driver by studies as an international measure regarding soil and land to be relevant everywhere, as well as in Europe. Many studies have linked laws and regulations associated with sustainable development to be applicable to soil health as well. Sustainable Development Goals (SDGs) are the international regulations that have been most identified to impact soil health everywhere, as well as in the EU, with specific exploration in Germany, Italy, and Greece. The regional institutional drivers regarding sustainability, the European Green Deal and the Renewable Energy Directive are expected to be influential in the EU. Laws and regulations regarding climate can be similarly influential for soil and land use. COP26 and the regional (i.e., EU Climate law and the Industrial Emission Directive) and some examples of the national adaptation have been identified by the studies to be influential for soil health as well. The EU's robust set of strategies and directives regarding waste and pollution is also considered to have a significant impact on the region's soil health. The region's laws and regulations regarding conservation (e.g. Biodiversity strategy, nature restoration law) have a wider set of objectives, and soil health is still considered to be within its influence by the studies. Certain local regulations, such as the Spanish Forest Plan, are also identified in the studies in this group. The combination of these global, regional, and local laws is identified to be relevant everywhere, with studies linking it specifically to Germany. Opposite to the synergy effect of the combination of laws and regulations, there is also the possibility of conflicts between the local and regional policies.

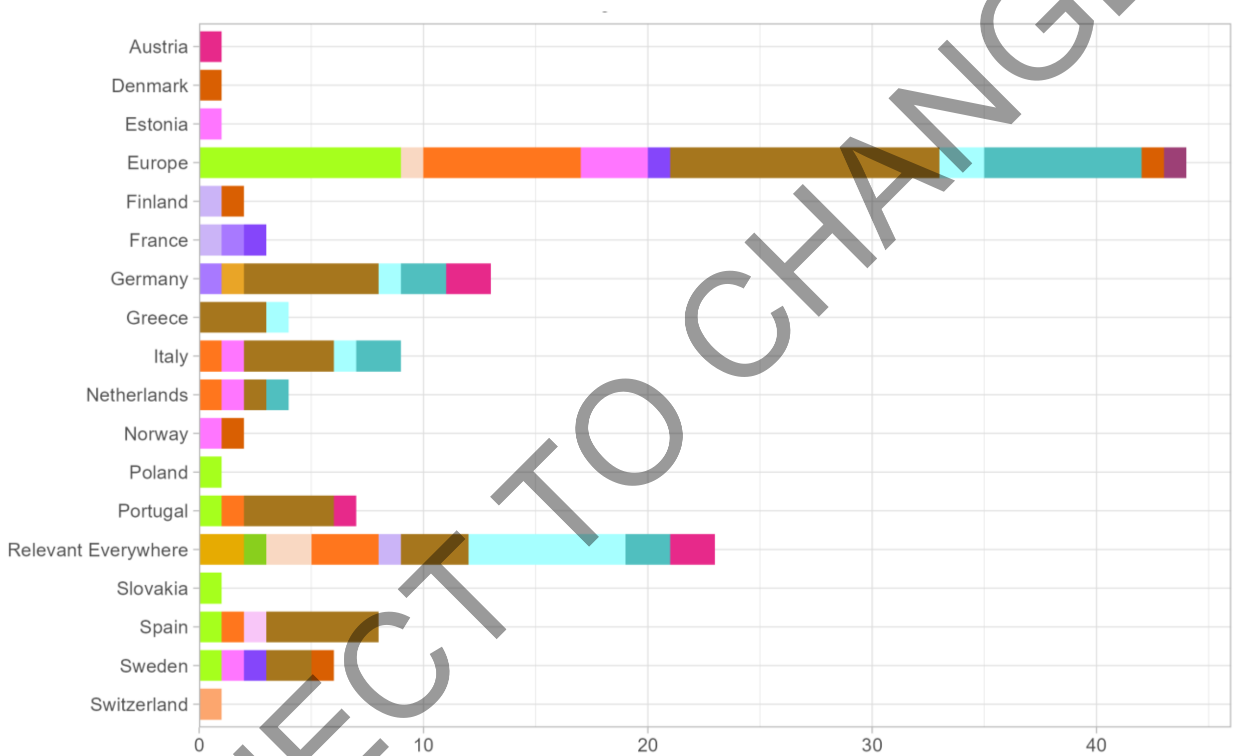

Figure 15: Political and institutional drivers for soil health across the EU (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 6. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.4.3 Distribution across soil health objectives

The bar chart in Figure 13 presents the distribution of the studies associated with different policy and institutional arrangement drivers across soil health objectives. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different policy and institutional arrangements drivers presented in Table 6. The most impacted soil health objective by the policy and institutional arrangements drivers is land degradation, followed by soil biodiversity and soil pollution. Soil structure is the least referenced, with no specific driver association with soil sealing.

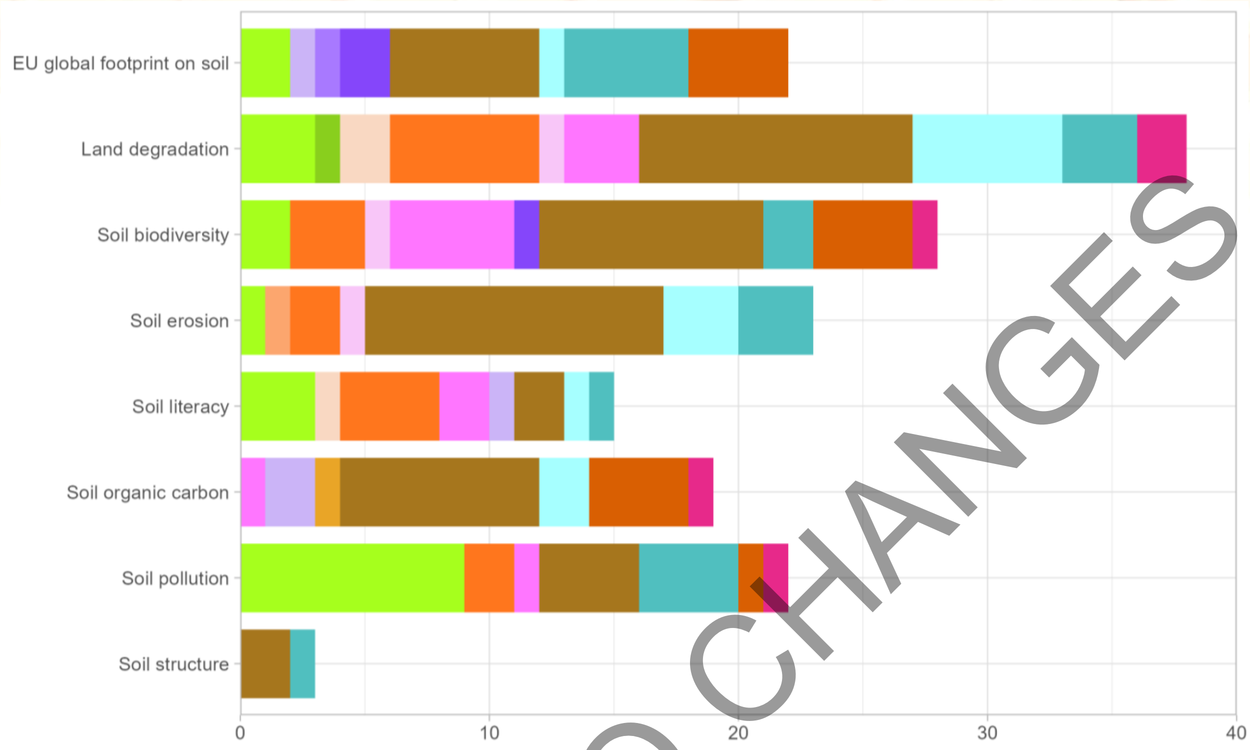

Figure 16: Political and institutional drivers for soil health across soil health objectives (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 6. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.5 Socio-cultural context

The following Table 7 presents the list of drivers related to the socio-cultural context. The drivers are then divided into generic and specific groups, with the specific drivers being associated with a generic driver. There are five generic drivers in this category, and two of the generic drivers are associated with four more specific drivers. The generic drivers are increasing societal demands for food security, increasing awareness and literacy of soil-based ecosystem services, land managers' attitude and willingness, lack of knowledge transfer between scientists and stakeholders, and changes in consumption patterns and demand. The drivers are colour-coded, and the colours were used in the following sections.

Table 7: Socio-cultural drivers for soil health

Generic	Specific
Increasing societal demands for food security	Increased interest in urban agriculture
Increasing awareness and literacy of soil-based ecosystem services	Growing concerns about soil health in industrial and urban areas
	Participatory decision making for land use planning and management
	Need for soil-related policies to reflect the need for societal demand.
Land managers' attitude and willingness	
Lack of knowledge transfer between scientists and stakeholders	
Changes in consumption patterns and demand	

4.5.1 Distribution across land-use type

The bar chart in Figure 17 presents the distribution of the studies associated with different drivers of socio-cultural context across the four land uses. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different drivers of socio-cultural context presented in Table 7. The highest share of studies has been linked to natural land use for socio-cultural drivers, with the main being changes in consumption patterns and demand. Agriculture is the second most referenced, but it was associated with all the drivers in this category. Urban land use has the smallest share of studies with reference to increasing awareness and literacy of soil-based ecosystem services.

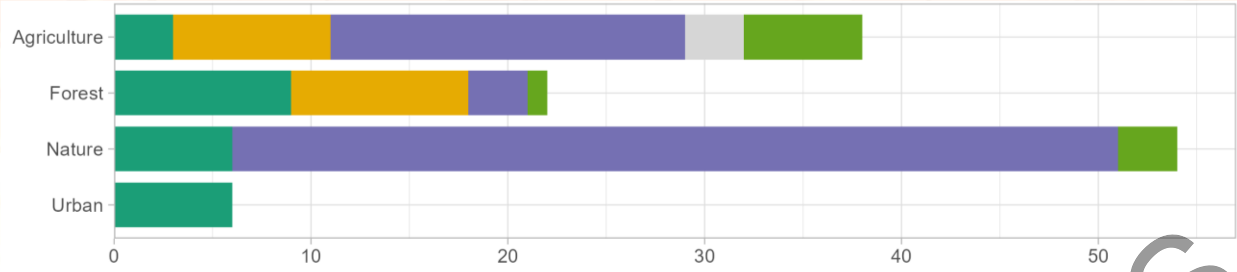

Figure 17: Socio-cultural drivers for soil health across land-use types (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 7. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.5.2 Distribution across the EU

The bar chart in Figure 18 presents the distribution of the studies associated with different drivers of socio-cultural context across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different drivers of socio-cultural context presented in Table 7. The most prominent socio-cultural driver is the changes in consumption patterns and demand, which studies expect to be relevant everywhere, with a significant impact in Spain, followed by Germany, Austria, France, and Italy. This driver is also expected to have an impact all over the EU, with studies relating it to the countries in the northern, as well as central and southern member states. A small set of studies also linked increasing demand for food security to be relevant everywhere, while highlighting the importance for the EU region. Many studies also identified a widespread trend of increasing awareness and literacy of soil-based ecosystem services, linking the driver to Italy, Finland, Sweden, Poland, Belgium, Germany, the Netherlands, Austria, France, Slovenia, Romania, Spain, and Portugal. There is, however, a growing counter-trend of scepticism regarding scientific knowledge. Lack of knowledge transfer between scientists and stakeholders encompasses these uncertainties as well as the challenges of communication between different groups of stakeholders associated with soil and land use. A large share of studies link this driver with Portugal, followed by Austria, with some studies establishing general relevance everywhere and the EU. Another driver influencing soil health is the land managers´ attitude and willingness. The driver can be related to, for example, land managers' willingness or lack thereof to adopt different practices or to participate in monitoring and scientific experiments. Studies have associated the driver with several countries across the EU.

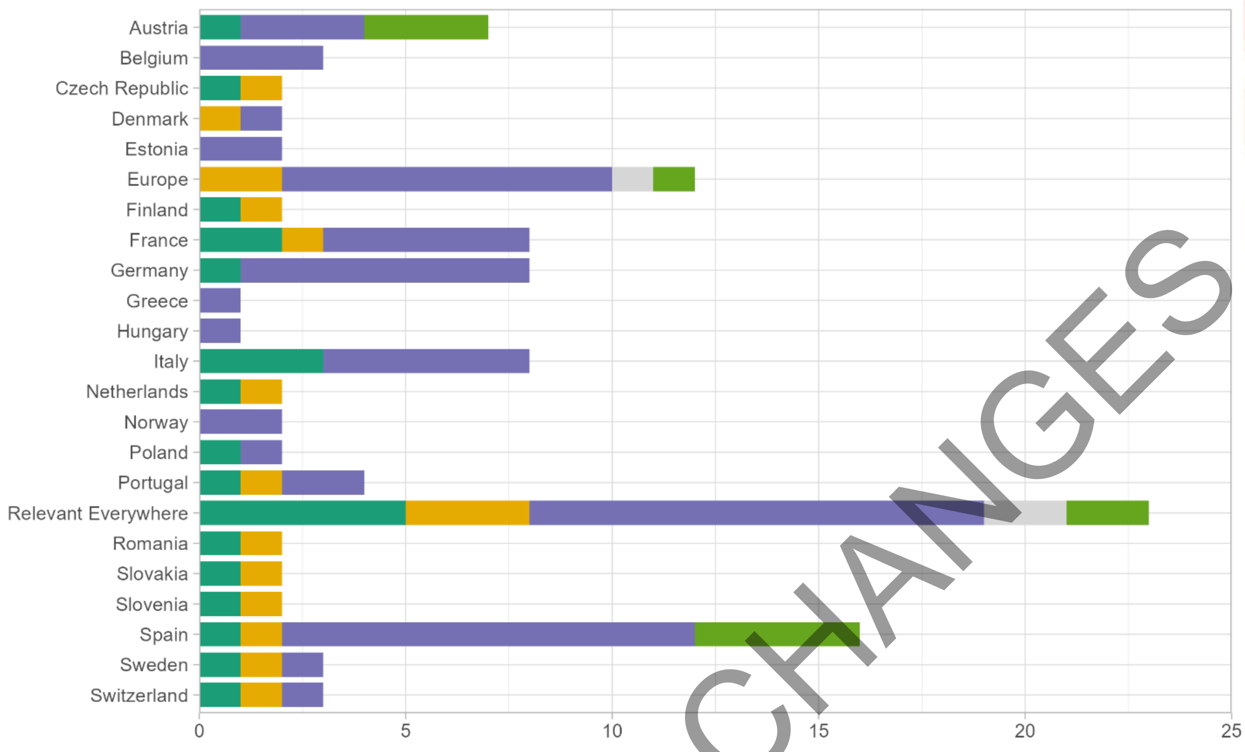

Figure 18: Socio-cultural drivers for soil health across the EU (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 7. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.5.3 Distribution across soil health objectives

The bar chart in Figure 19 presents the distribution of the studies associated with different drivers of socio-cultural context across soil health objectives. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different drivers of socio-cultural context presented in Table 7. The aspect of soil health most associated with socio-economic drivers in the highest number of studies is soil literacy. The share of the studies linking the most prominent driver in this category, changes in consumption patterns and demand, is, however, low for soil literacy, but is the main influential driver for the three following most linked soil health objectives: land degradation, SOC, and soil biodiversity. Soil sealing, on the other hand, is linked mainly with increasing awareness and literacy of soil-based ecosystem services, which is also the driver most linked by the studies to soil literacy. Land managers' attitude and willingness are also largely associated with soil literacy, with studies linking it with the rest of the soil health objectives except soil sealing.

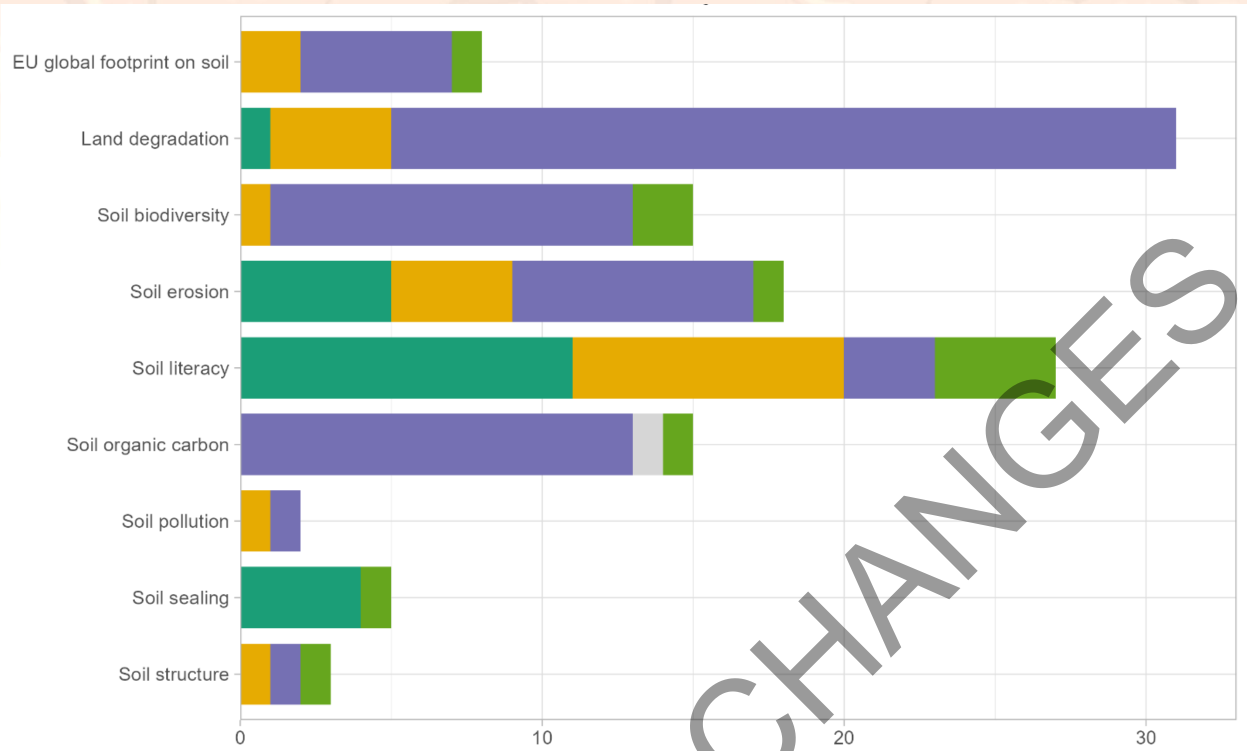

Figure 19: Socio-cultural drivers for soil health across soil health objectives (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 7. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.6 Economy

The following Table 8 presents the list of drivers related to the socio-cultural context. The drivers are then divided into generic and specific groups, with the specific drivers being associated with a generic driver. There are eight generic drivers in this category, and three of the generic drivers are associated with ten more specific drivers. The generic drivers are: increasing demand for renewables, market pressure and volatility, expansion of built-up areas, historical mining, armed conflicts, improved access to the global market, and improved access to the global market. The drivers are colour-coded, and the colours were used in the following sections.

Table 8: Economic drivers for soil health

	Generic	Specific
	Increasing demand for renewables	Increasing demand for bioenergy
		Increasing demand for solar energy
		Emerging carbon markets
	Market pressure and volatility	Market volatility
		Decreasing market price
		Increasing market price
	Expansion of built-up areas	Urbanisation
		Increasing demand for industrial areas
		Non-favourable economic conditions in rural areas
		Expansion of rural settlements
	Historical mining	
	Armed conflicts	
	Improved access to the global market	
	Increasing demand for tourism/recreational use	
	Increasing demand for food	

4.6.1 Distribution across land-use type

The bar chart in Figure 20 presents the distribution of the studies associated with different economic drivers for the four land-uses. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. Agricultural land use has the most studies linking it to all economic drivers. The colour coding refers to the different economic drivers presented in Table 8. Alternatively, soil erosion has the fewest number of studies associated with it, but can be linked back to all economic drivers except historical mining, which is associated with only urban and industrial land-use. While urban areas have the second largest share of studies linked to the economic drivers, increasing demand for food was not one of them, which was linked to the rest. Most studies for increasing demand for renewables link it to agriculture, with some connection to forest land-use.

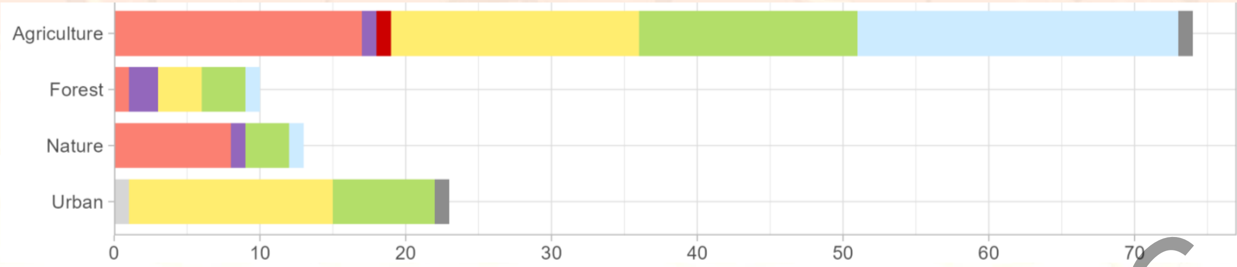

Figure 20: Economic drivers for soil health across land-use types (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 8. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.6.2 Distribution across the EU

The bar chart in Figure 21 presents the distribution of the studies associated with different economic drivers across the EU. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different economic drivers presented in Table 8. The spatial distribution of economic drivers is well spread across the member states of the EU, and the largest set of studies linked the drivers within the economy category to be relevant everywhere, except armed conflicts, which studies linked to Ukraine and past or present active war zones. Several regions associated with the drivers are characterised by their geographic location, environmental or climatic conditions. While the peat lands and drylands are impacted by the market pressure and volatility and increased demands for renewables, the increasing demand for food is identified to largely affect the Mediterranean region, as well as the two aforementioned drivers. The largest number of studies linking economic drivers to is Spain, followed by Germany. Market pressure and volatility are also linked to a wider set of countries. Expansion of built-up areas is another driver with widespread impact across the EU member states, with Spain being the most associated, followed by Italy. Studies also linked the driver with Austria, France, Slovakia, Albania, Greece, Poland, the Czech Republic, the Netherlands, Germany, Slovenia, Sweden, and Finland. Increasing demand for renewables is similarly found to be linked with many EU member states: Germany, Italy, France, Spain, Sweden, Ukraine, and the Netherlands. Increasing demand for tourism and other recreational uses has been identified as a driver to be relevant everywhere, and specifically in Finland. Historical mining is another driver associated with a single country, the Czech Republic.

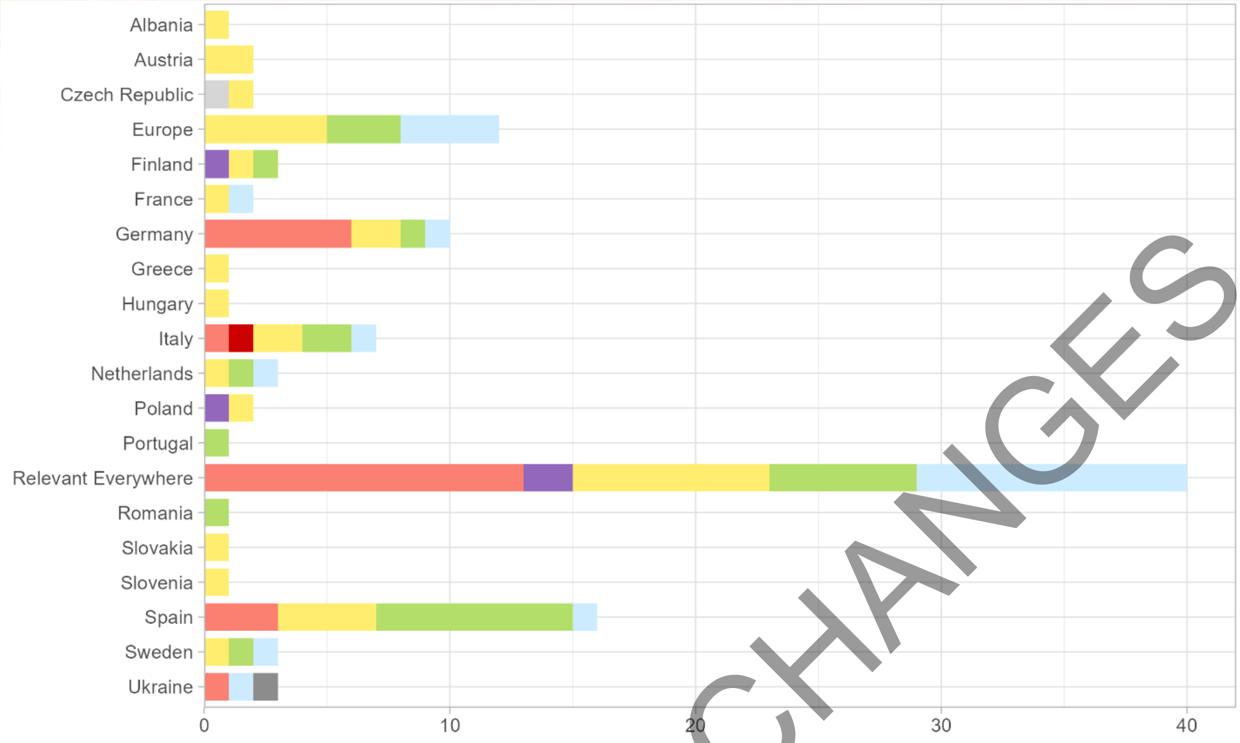

Figure 21: Economic drivers for soil health across the EU (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 8. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

4.6.3 Distribution across Soil health objectives

The bar chart in Figure 22 presents the distribution of the studies associated with different economic drivers across soil health objectives. Point to be noted for all the bar plots is that one study can be referenced to multiple drivers. The colour coding refers to the different economic drivers presented in Table 8. The impact of these drivers on soil health can also be very specific for certain objectives. Soil sealing is only associated with the driver expansion of built-up area and is also the soil health objective most explored. Impact on soil structure and soil literacy is also limited to this driver, and for a large part, to market pressure and volatility. Alternatively, soil erosion has the fewest number of studies associated with it, but can be linked back to all economic drivers except armed conflict, which is linked to land degradation.

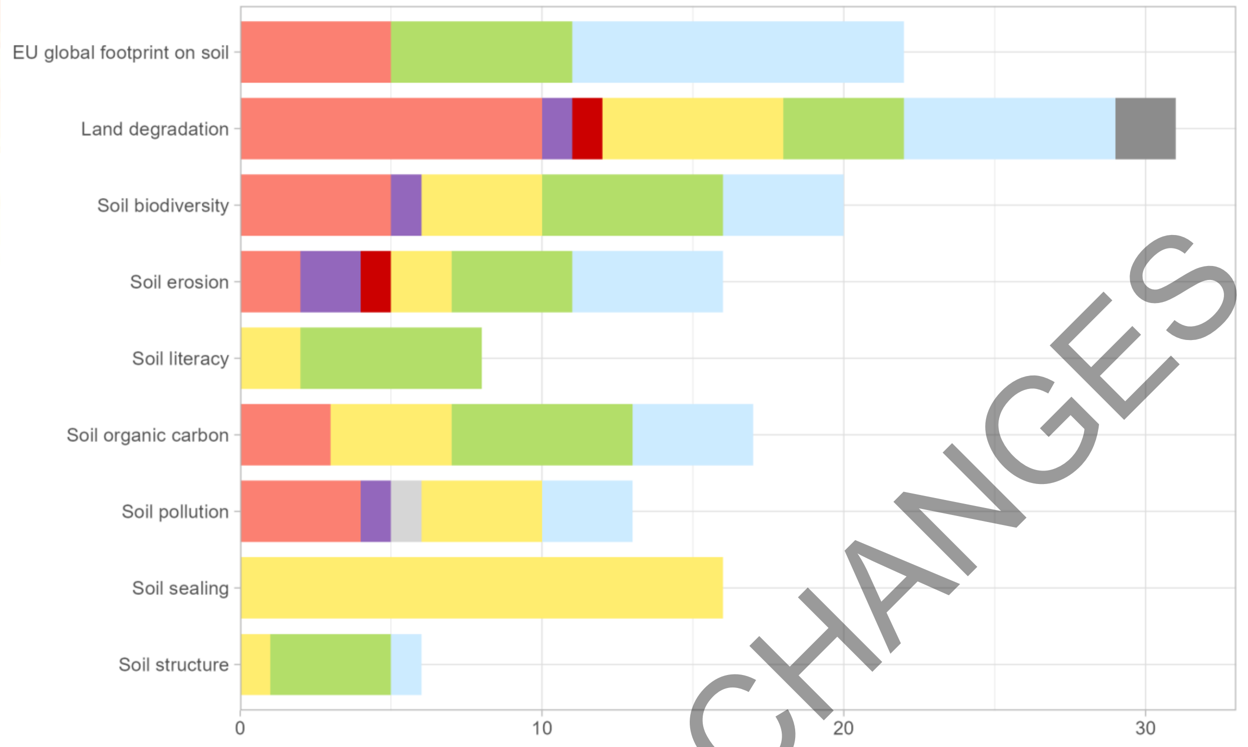

Figure 22: Economic drivers for soil health across soil health objectives (The colour coding refers to the different policy and institutional arrangements drivers presented in Table 8. X-axis refers to the number of studies associated, one study can be linked to multiple drivers)

5 Pressures - Changes in use, intensity, or quality of land-use and soil management

The DPSIR framework, adapted for the SOLO meta-analysis as per the work protocol (see Chapter 2), describes the pressures as the changes the driver causes on soil and land. The changes across land-use and soil management are identified as changes caused by the drivers in land-use, land management, and the quality of management. These changes are explored in association with the different land-uses in the following sections. The changes are standardised to follow, which is different for specific changes. For land-use change, selections were made from the following options: same, change, possibly change, and unsure. For changes in intensity, selections were made from the following options: increase, possibly increase, decrease, change, possibly decrease, possibly change, and unsure. For changes in management quality, selections were made from the following options: improve, possibly improve, deteriorate, possibly deteriorate, change, possibly change, and unsure.

5.1 Soil and land pressures in Agriculture

Agricultural land-use in this study can be correlated to the land-use Class 1 Agricultural areas according to the Corine Land Cover (CLC) classifications (Kosztra et al., 2019). The land-use is further divided into four main types and eleven associated sub-types elaborated in Table 9. Selected studies of the meta-analysis are explored to identify the type of agricultural land use and the type of changes taking place. It was not possible for many studies to have more detailed information on the land-use type other than agriculture; a lot of studies could be further detailed out to different sub-types and associated changes. Studies that have differentiated between different types of agricultural land (i.e. relevant everywhere) are not listed in the following sections.

Table 9: Agriculture land-use types and sub-types

Main type	Sub-type
Arable land	Non-irrigated arable land
	Permanently irrigated arable land.
	Rice fields
Permanent crops	Vineyards
	Fruit tree and berry plantations
	Olive groves
Pastures	Pastures
Heterogeneous agricultural areas	Annual crops associated with permanent crops
	Complex cultivation patterns
	Land principally occupied by agriculture, with significant areas of natural vegetation
	Agro-forestry areas

5.1.1 Arable land

Arable land is described in the CLC classification as ‘Lands under a rotation system used for annually harvested plants and fallow lands, which are rain-fed or irrigated. Includes flooded crops such as rice fields and other inundated croplands (Kosztra et al., 2019). Within this main type of agricultural land-use, three sub-types: non-irrigated arable land, permanently irrigated land, and rice fields. There are several studies that can be related to permanently irrigated land (Table 11), while many studies are associated with the main type, arable land (Table 10).

Table 10: Drivers for changes in land-use and soil management for arable land

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Adoption of Nature-based solutions and Sustainable practices	Europe	(Carrer et al., 2018)	Same	Unsure	Possibly improve
Nature and environments					
Climate change	Relevant everywhere	(Hastings et al., 2013)	Same	Unsure	Possibly change
Climate change - Shift in precipitation, temperature, and wind patterns		(Abdalla et al., 2014)	Same	Unsure	Possibly change
Climate change - Increased temperature	Europe	(Kourgialas , 2021)	Same	Unsure	Change
Policy and institutional arrangements					
National - National legislations and laws - Laws or regulations regarding climate - Renewable Energy Act (German: EEG)	Germany	(Lupp et al., 2015)	Change (Biofuel cultivation)	Possibly increase	Change
EU - EU level directives and legislations - Laws or regulations regarding agriculture - Common Agricultural Policy (CAP)					
EU - EU level strategies, agreements and conventions - Laws or regulations regarding Sustainable development - Renewable Energy Directive	Italy	(Serra et al., 2017)	Same	Unsure	Possibly improve
EU - EU level directives and legislations - Laws or regulations regarding agriculture- Nitrates Directive	EU	(Kolasa-Więcek, 2015)	Same	Unsure	Possibly improve

Socio-cultural context					
Changes in consumption patterns and demand	EU	(Saget et al., 2020)	Possibly change	Possibly change	Possibly improve
Changes in consumption patterns and demand	EU	(Bais-Moleman et al., 2019)	Same	Unsure	Possibly improve
Economy					
Increasing demand for food	Relevant everywhere	(Smerald et al., 2022)	Same	Increase	Possibly change

Apart from demographic drivers, drivers from all the other categories are identified to impact arable land (Table 10). Climate change, relevant globally, can potentially alter management practices. Technology and management driver - adoption of nature-based solutions and sustainable practices in Europe could potentially drive improvement in management quality without influencing changes in use or intensity of land-use. Policy drivers such as the EU's Common Agricultural Policy and Renewable Energy Directive can push for arable land towards biofuel cultivation and possible improvements in management quality. Socio-cultural drivers - shifts in consumption patterns and economic drivers – increasing demands for food can also lead to increased intensity and uncertain management outcomes.

Table 11: Drivers for changes in land-use and soil management for arable land - Permanently irrigated land

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Advancement in tools and models for soil monitoring and land management - Water	Spain	(Robinson et al., 2012)	Same or change	Possibly decrease	Possibly improve
		(Martínez-Cortijo & Ruiz-Canales, 2018)	Same	Unsure	Change
Adoption of Nature-based solutions and Sustainable practices	Switzerland	(Yang et al., 2021)	Same	Decrease	Improve
	Spain	(Robinson et al., 2012)	Same or change	Possibly decrease	Possibly improve
Nature and environments					
Climate change - Increased temperature	Portugal	(Tomaz et al., 2020)	Same	Unsure	Possibly change

	Spain	(Robinson et al., 2012)	Same or change	Possibly decrease	Possibly improve
Climate change - Shift in precipitation, temperature, and wind patterns	Spain	(Robinson et al., 2012)	Same or change	Possibly decrease	Possibly improve
<u>Policy and institutional arrangements</u>					
EU - EU level directives and legislations - Laws or regulations regarding agriculture - Common Agricultural Policy (CAP)	EU	(Zander et al., 2016)	Same or change	Unsure	Possibly change
<u>Socio-cultural context</u>					
Changes in consumption patterns and demand	EU	(Zander et al., 2016)	Same or change	Unsure	Possibly change
Land managers' attitude and willingness			Same or change	Unsure	Possibly change
<u>Economy</u>					
Market pressure and volatility	EU	(Zander et al., 2016)	Same or change	Unsure	Possibly change

Table 11 focuses on specifically permanently irrigated arable land, which can be described as, 'Cultivated land parcels under agricultural use for arable crops that are permanently or periodically irrigated, using a permanent infrastructure (irrigation channels, drainage network and additional irrigation facilities)' (Kosztra et al., 2019). Similar to arable land, drivers from all categories except demography have been found to be specific to changes in permanently irrigated land. Advancements in tools and models for soil monitoring and land management – Water and the Adoption of Nature-based solutions and Sustainable practices are found to improve management quality in Spain and Switzerland. Climate change drivers, increased temperature and shift in precipitation, temperature, and wind patterns, are linked to uncertain intensity changes and possible improvements in management. Policy and institutional driver – CAP can potentially influence changes in land-use, intensity and management.

Although peat soil is a separate land-use under forest and semi-natural areas according to CLC classification, certain studies focus on agriculture specifically occurring on peat soil. Table 12 highlights the drivers associated with this particular land-use. CAP is also identified in this land-use to inflict changes in use, intensity, and management. Socio-cultural context drivers - Changes in consumption patterns and demand, and Land managers' attitude and willingness, can possibly lead to use and management with increasing intensity. Economic driver - market pressure and volatility, can also lead to changes in all three change categories.

Table 12: Drivers for changes in land-use and soil management for arable land on peat soil

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Policy and institutional arrangements					
EU - EU level directives and legislations - Laws or regulations regarding agriculture - Common Agricultural Policy (CAP)	Netherlands	(Norris et al., 2021)	Same or change	Possibly increase	Change
	Relevant everywhere	(Buschmann et al., 2020)	Possibly change	Possibly change	Possibly change
Socio-cultural context					
Changes in consumption patterns and demand	Germany	(Beyer et al., 2015)	Change	Increase	Change
Land managers' attitude and willingness	Netherlands	(Norris et al., 2021)	Same or change	Possibly increase	Change
Economy					
Market pressure and volatility	Relevant everywhere	(Buschmann et al., 2020)	Possibly change	Possibly change	Possibly change

5.1.2 Permanent crops

Permanent crops are defined by CLC classification, ´All surfaces occupied by permanent crops, not under a rotation system. Includes ligneous crops of standard cultures for fruit production, such as extensive fruit orchards, olive groves, chestnut groves, walnut groves, shrub orchards such as vineyards and some specific low-system orchard plantations, espaliers and climbers (Kosztra et al., 2019). Table 13 summarises the drivers relevant to this land-use. All driver categories, apart from policy and institutional drivers, are present for this land-use. Technology and management drivers, Advancement in tools and models for soil monitoring and land management – Water, Advancement in tools and models for soil monitoring and land management - Management and planning, Adoption of Nature-based solutions and Sustainable practices, Current land management practice – Water can potentially increase land-use intensity and improve management. Nature and environment driver - Climate change - shift in precipitation, temperature, and wind patterns, and demographic drivers, increasing population, additional pressure, and potentially increasing land-use intensity as well. Socio-cultural context driver, changes in consumption patterns, and demand are expected to change intensity and improve management. Economic drivers, Market pressure and volatility and increasing demand for food can influence intensity and management quality.

Table 13: Drivers for changes in land-use and soil management for permanent crops

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Advancement in tools and models for soil monitoring and land management - Water	Relevant everywhere	(Schultz & Stoll, 2010)	Same or change	Possibly increase	Possibly change
Advancement in tools and models for soil monitoring and land management - Management and planning					
Adoption of Nature-based solutions and Sustainable practices					
Current land management practice - Water					
Nature and environments					
Climate change - Shift in precipitation, temperature, and wind patterns	Relevant everywhere	(Schultz & Stoll, 2010)	Same or change	Possibly increase	Possibly change
Demography					
Increasing population	Relevant everywhere	(Schultz & Stoll, 2010)	Same or change	Possibly increase	Possibly change
Socio-cultural context					
Changes in consumption patterns and demand	Spain	(González-Rosado et al., 2023)	Same	Change	Improve
Economy					
Market pressure and volatility	Spain	(González-Rosado et al., 2023)	Same	Changed	Improve
	Spain	(Parras-Alcántara et al., 2013)	Change	Unsure	Change
Increasing demand for food	Relevant everywhere	(Schultz & Stoll, 2010)	Same or change	Possibly increase	Possibly change

There are three sub-types of permanent crop land-use: vineyards, fruit tree and berry plantations, and olive groves. Table 14 summarises the drivers relevant to vineyards. Studies have associated various drivers with influencing changes largely in vineyards located in Spain and Portugal. Nature and environment drivers, Climate change - Shift in precipitation, temperature, and wind patterns and extreme weather can lead to deteriorating management and increased intensity. Socio-cultural context drivers, Lack of knowledge transfer between scientists and stakeholders, and Land managers' attitude and willingness can also intensify change and worsen management quality. Policy and institutional drivers, the Water Framework Directive and the EU soil strategy can, however, improve management quality. Technology and management drivers, Advancement in tools and models for soil monitoring and land management – Water and Adoption of Nature-based solutions and Sustainable practices can influence improving management quality as well.

Table 14: Drivers for changes in land-use and soil management for permanent crops - vineyards

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Advancement in tools and models for soil monitoring and land management - Water	Spain	(Marques et al., 2015)	Same	Possibly change	Possibly change
Adoption of Nature-based solutions and Sustainable practices	Portugal	(C. S. S. Ferreira et al., 2018)	Same	Unsure	Improve
<u>Nature and environments</u>					
Climate change - Shift in precipitation, temperature, and wind patterns	Spain	(Marques et al., 2015)	Same	Possibly change	Worse
Climate change - Extreme weather	Portugal	(C. S. S. Ferreira et al., 2018)	Same or change	Possibly increase	Possibly change
<u>Policy and institutional arrangements</u>					
EU -EU level directives and legislations - Laws or regulations regarding waste and pollution - Water Framework Directive EU - EU level strategies, agreements and conventions - Laws or regulations regarding soil and land - EU soil strategy	Portugal	(C. S. S. Ferreira et al., 2018)	Same	Unsure	Improve

Socio-cultural context					
Lack of knowledge transfer between scientists and stakeholders Land managers' attitude and willingness	Spain	(Marques et al., 2015)	Same	Possibly change	Worse

Table 15 summarises the drivers relevant to fruit tree and berry plantations. Demography driver, ageing, and economic driver, market pressure and volatility, can both result in reduced intensity and change in management, as the drivers might lead to abandonment of practice.

Table 15: Drivers for changes in land-use and soil management for permanent crops – fruit tree and berry plantations

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Demography					
Aging	Spain	(Cerdà et al., 2019)	Change/ abandoned	Decrease	Change
Economy					
Market pressure and volatility	Mediterranean	(Cerdà et al., 2019)	Change/ abandoned	Decrease	Change

Table 16 summarises the multiple drivers found relevant for olive groves. Olive groves are influenced by current management practices, sustainable approaches, and climate change. Technology and management drivers, Current land management practice related to Soil amendments and machinery can result increase in intensity, while the Adoption of Nature-based solutions and Sustainable practices can result in improvement in management. Nature and environment drivers related to different climate change phenomena can see changes in intensity and management. Demographic drivers - Declining rural population and ageing can bring on changes as well to the intensity.

Table 16: Drivers for changes in land-use and soil management for permanent crops – olive groves

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Current land management practice - Soil amendments and machinery	Spain	(Archidona-Yuste et al., 2021; García-Ruiz, 2010)	Same	Increase	Change
Current land management practice					
Adoption of Nature-based solutions and Sustainable practices	Relevant everywhere	(Jones, 2016)	Same or changed	Possibly increased	Unsure
	Spain	(Vicente-Vicente et al., 2017)	Same	Same	Improve
Nature and environments					
Climate change - Increased precipitation	Relevant everywhere	(Jones, 2016)	Same or change	Possibly increase	Unsure
Climate change - Shift in precipitation, temperature, and wind patterns					
Climate change - Extreme weather					
Climate change - Prolongation of the growing season due to a warming climate	Sweden, Finland, Norway, Denmark				
Demography					
Migration - Declining rural population	Spain	(García-Ruiz, 2010)	Changed/abandoned	Decreased	Change
Ageing - Decline in active labour in agriculture	Portugal	(Jones, 2016)	Same or changed	Possibly increased	Unsure
Policy and institutional arrangements					
EU - EU level directives and legislations - Laws or regulations regarding agriculture - Common Agricultural Policy (CAP)	Spain	(Vicente-Vicente et al., 2017)	Same	Same	Improve

Socio-cultural context					
Changes in consumption patterns and demand	Spain	(Archidona-Yuste et al., 2021)	Changed	Increased	Unsure
Economy					
Increasing demand for renewables	EU	(Solinas et al., 2021)	Same	Same	Improve

5.1.3 Pasture

Pastures are defined by CLC classification, ´Lands that are permanently used (at least 5 years) for fodder production. Includes natural or sown herbaceous species, unimproved or lightly improved meadows and grazed or mechanically harvested meadows. Regular agriculture influences the natural development of natural herbaceous species composition (Kosztra et al., 2019). Table 17 summarises the drivers relevant to this land-use.

Several technology and management drivers are identified to be influential everywhere, especially in Spain, possibly resulting in an increase in intensity and improved management quality, while nature and environment drivers, such as climate change, may potentially worsen the management quality. While advancements in soil monitoring and sustainable practices generally maintain land use, climate extremes in Spain increase intensity and may worsen management quality. Policy and institutional drivers, such as the Common Agricultural Policy (CAP) and Strategic Approach to Pharmaceuticals in the Environment, can potentially lead to a decrease in use intensity and improvement in management, especially in Germany. Economic driver, Market pressure and volatility can lead to an increase in intensity and lead to worsening management quality.

Table 17: Drivers for changes in land-use and soil management for pasture

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Advancements in tools and models for soil monitoring and land management - Management and planning	Relevant everywhere	(Kath et al., 2019)	Same or change	Possibly decrease	Unsure
	Spain	(Pardo et al., 2016)	Same	Unsure	Improve
Advancements in tools and models for soil monitoring and land management	EU	(Rodríguez et al., 2022)	Same	Unsure	Possibly improve
Current land management practice	Spain	(Rodríguez et al., 2022)	Same	Possibly increased	Unsure
Current land management practice - Waste and pollution	EU	(Rodríguez et al., 2022)	Same	Possibly increased	Unsure
Adoption of Nature-based solutions and Sustainable practices	Spain	(Díaz de Otálora et al., 2021)	Same	Unsure	Improve
	Spain	(Pardo et al., 2016)	Same	Unsure	Improve
Nature and environments					
Climate change - Increased temperature	Relevant everywhere	(Kath et al., 2019)	Same or change	Possibly decrease	Unsure
Climate change - Shift in precipitation, temperature, and wind patterns	Spain	(Pardo et al., 2016)	Same	Increase	Possibly worse
Climate change - Extreme weather					
Policy and institutional arrangements					
EU - EU level strategies, agreements and conventions- Laws or regulations regarding waste and pollution - Strategic Approach to Pharmaceuticals in the Environment	EU	(Rodríguez et al., 2022)	Same	Possibly increase	Unsure
EU - EU level directives and legislations - Laws or regulations regarding agriculture - Common Agricultural Policy (CAP)	Spain	(Fernández-Guisuraga et al., 2022)	Change	Decrease	Change
	Germany		Same	Decrease	Improve

EU - EU level strategies, agreements and conventions- Laws or regulations regarding waste and pollution - Strategic Approach to Pharmaceuticals in the Environment		(Früh-Müller et al., 2019)(Renwick et al., 2013)			
Economy					
Market pressure and volatility	Spain	(Fernández-Guisuraga et al., 2022)	Change	Decrease	Change
	Spain	(Pardo et al., 2016)	Same	Increase	Possibly worse

Although there is no subdivision in pasture land-use, this particular subdivision for pasture land related to cattle farming is made, as these studies refer to intensive farming. The drivers associated are summarised in Table 18. Adoption of Nature-based solutions and Sustainable practice - Soil amendments and machineries can potentially improve management quality in Greece, while extreme weather as a result of climate change might bring about changes everywhere. Demographic driver – increasing population may influence changes in management, and policy and institutional driver, the Water Framework Directive may potentially improve management across the EU. Similarly, economic drivers, increasing demand for food, may influence uncertain changes and increasing demand for tourism/recreational use may improve management quality.

Table 18: Drivers for changes in land-use and soil management for pasture (cattle farming)

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Adoption of Nature-based solutions and Sustainable practice - Soil amendments and machinery	Greece	(Anestis et al., 2015)	Same	Unsure	Possibly improve
Nature and environments					
Climate change - Extreme weather	Relevant everywhere	(Kourgialas, 2021)	Same	Unsure	Possibly change
Demography					
Increasing population	Relevant everywhere	(Hastings et al., 2013)	Same	Unsure	Possibly change

Policy and institutional arrangements					
EU -EU level directives and legislation - Laws or regulations regarding waste and pollution - Water Framework Directive	EU	(Kolasa-Więcek, 2015)	Same	Unsure	Possibly improve
Economy					
Increasing demand for food	Relevant everywhere	(Fowler et al., 2015)	Same	Unsure	Possibly change
Increasing demand for tourism/recreational use	Relevant everywhere	(Kourgialas, 2021)	Same	Unsure	Possibly improve

5.1.4 Heterogeneous agricultural areas - Agro-forestry areas

Heterogeneous agricultural areas are defined by CLC classification, ´Areas of annual crops associated with permanent crops on the same parcel, annual crops cultivated under forest trees, areas of annual crops, meadows and/or permanent crops which are juxtaposed, landscapes in which crops and pastures are intimately mixed with natural vegetation or natural areas´ (Kosztra et al., 2019). Although there are four different sub-types for heterogeneous agricultural areas, specific studies have been found only for Agro-forestry areas, which are defined as ´Annual crops or grazing land under the wooded cover of forestry species´ (Kosztra et al., 2019). The drivers for this are listed in Table 19. Current land management practice may lead to a decrease in intensity in France, while policy and institutional drivers, the nitrates Directive, may lead to improvement in Portugal. Economic driver, increasing demand for renewable energy may lead to changes in both use and management for this land-use everywhere.

Table 19: Drivers for changes in land-use and soil management for Heterogeneous agricultural areas - Agro-forestry areas

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Current land management practice	France	(Drewer et al., 2016)	Unsure	Possibly decrease	Unsure
Policy and institutional arrangements					
EU - EU level directives and legislations - Laws or regulations regarding Sustainable	EU	(Drewer et al., 2016)	Unsure	Possibly decrease	Unsure

development - Renewable Energy Directive					
EU - EU level directives and legislations - Laws or regulations regarding agriculture - Nitrates Directive	Portugal	(Cameira et al., 2019)	Same	Not sure	Improve
Economy					
Increasing demand for renewables	Relevant everywhere	(Drewer et al., 2016)	Change	Unsure	Possibly change

5.1.5 Agricultural land in the past and present active warzone

Although not specific to any particular agricultural land-use types, armed conflicts (Table 20) will bring forward changes in the agricultural areas located in past and present active war zones.

Table 20: Drivers for changes in land-use and soil management for agricultural land in past and present active warzones

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Economy					
Armed conflicts	Past and present active war zones	(Pereira et al., 2020)	Change	Change	Change

5.2 Soil and land pressures in Forestry

Although in CLC classification, forestry is included in forest and semi-natural areas, we divided them into two parts, with forestry in one, and the rest are included under natural areas. This division of land-use is in line with the preceding EU soil mission projects, SMS, and PrepSoil. Forest is defined as. ´Areas occupied by forests and woodlands with a vegetation pattern composed of native or exotic coniferous and/or broad-leaved trees and which can be used for the production of timber or other forest products´ (Kosztra et al., 2019). There are three subtypes: broad-leaved forest, coniferous forest, and mixed forest. Studies have been found in association with broad-leaved forest and mixed forest.

5.2.1 Coniferous forest

Table 21 lists the drivers for the coniferous forest, which is defined as ´Vegetation formation composed principally of trees, including shrub and bush understorey, where coniferous species predominate´(Kosztra et al., 2019). Studies have identified current technology and management drivers bringing changes in coniferous forests in Finland, Norway, and Sweden, which potentially lead to a decrease in intensity.

Table 21: Drivers for changes in land-use and soil management for coniferous forest

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Current land management practice	Finland	(Piirainen et al., 2007)	Change	Change	Change
	Norway	(Huusko et al., 2015)	Change	Change	Change
Current land management practice - Soil amendments and machinery	Finland	(Smolander et al., 2019)	Change	Same	Change
	Sweden	(Kim et al., 2021)	Change	Decrease	Change

5.2.2 Mixed forest

Table 22 lists the drivers for the mixed forest, which is defined as ´Vegetation formation composed principally of trees, including shrub and bush understorey, where neither broad-leaved nor coniferous species predominate´(Kosztra et al., 2019). Studies have identified several technology and management drivers bringing changes across mixed forests. Current land management practices related to soil amendments and machinery can potentially lead to changes in the land-use and intensity, as well as possibly worsening the management. Recognition of the need for efficient spatial planning strategies across all land uses in association with management and planning is found to be influencing positive changes in the use and management everywhere.

Table 22: Drivers for changes in land-use and soil management for mixed forest

Driver	Location	Citation	Land use change	Intensity change	Management quality change
Technology and Management					
Recognition of the need for efficient spatial planning strategies across all land uses - Management and planning.	Spain	(Barberá et al., 2019)	Same	Unsure	Possibly change
	Relevant everywhere	(Korboulewsky et al., 2016)	Change	Change	Change
Current land management practice - Soil amendments and machinery	EU (Temperate, Boreal)	(Barberá et al., 2019)	Change	Possibly change	Worse

5.3 Soil and land pressures in Nature

As explained in the forestry section, natural areas for this study are a mix of the rest of the land uses under forest and semi-natural areas and the wetlands. This division of land-use is in line with the preceding EU soil mission projects, SMS, and PrepSoil. Table 23 comprises the main types and sub-types within natural areas. The main types are shrub and/or herbaceous vegetation associations, open spaces with little or no vegetation, and wetlands.

Table 23: Nature land-use types and sub-types

Main type	Sub-type
Shrub and/or herbaceous vegetation associations	Natural grassland
	Moors and heathland
	Sclerophyllous vegetation
	Transitional woodland/shrub
Open spaces with little or no vegetation	Beaches, dunes, sands
	Bare rock

	Sparsely vegetated areas
	Burnt areas
	Glaciers and perpetual snow
Wetlands	Inland wetlands (marshes, peatbogs)
	Coastal wetlands (salt marshes, salines, intertidal flats)

5.3.1 Natural grassland

Natural grassland is a subtype within shrub and/or herbaceous vegetation associations, which can be described as ´Grasslands under no or moderate human influence. Low-productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes, frequently including rocky areas or patches of other (semi-)natural vegetation (Kosztra et al., 2019). Table 24 summarises the drivers, which are from the nature and environment category, found relevant for this land-use. Climate change impact at large on grassland in Germany might potentially bring forward changes in land-use, which may result in increased intensity and influence management quality. Other specific climate change-related drivers, such as increased temperature and decreased precipitation, may result in changes in use in France as well, which can lead to decreased intensity and improved management.

Table 24: Drivers for changes in land-use and soil management for natural grassland

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Nature and environments					
Climate change	Germany	(Zistl-Schlingmann et al., 2020)	Change	Increase	Change
Climate change - Increased temperature	France	(Meersmans et al., 2016)	Change	Possibly decrease	Improve
Climate change - Decreased precipitation	France	(Meersmans et al., 2016)	Change	Possibly decrease	Improve

5.3.2 Moors and heathland

Moors and heathland a subtypes within shrub and/or herbaceous vegetation associations, which can be described as, ´Vegetation with low and closed cover, dominated by bushes, shrubs, dwarf shrubs (heather, briars, broom, gorse, laburnum etc.) and herbaceous plants, forming a climax stage of development´ (Kosztra et al., 2019). Table 25 summarises the drivers, which are from technology and management and nature and environment categories, found relevant for this land-use. Current land management practices associated with soil amendments and machinery, and increased temperature associated with climate change, can potentially bring changes to use, which can lead to intensity and management of the land.

Table 25: Drivers for changes in land-use and soil management for moors and heathland

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Current land management practice- Soil amendments and machinery	Europe	(Fagúndez , 2013)	Possibly change	Possibly change	Possibly change
Nature and environments					
Climate change - Increased temperature	Europe	(Fagúndez , 2013)	Possibly change	Possibly change	Possibly change

5.3.3 Sclerophyllous vegetation

Sclerophyllous vegetation is a subtype within shrub and/or herbaceous vegetation associations, which is defined as ´Bushy sclerophyllous vegetation in a climax stage of development, including maquis, matorral and garrigue´ (Kosztra et al., 2019). Table 26 summarises the drivers, which are from nature and environment and socio-cultural context categories, found relevant for this land-use. Climate change drivers, such as increased temperature and extreme weather, can potentially trigger changes in this land-use in Spain, which can lead to decreased intensity and a change in management. Changes in consumption patterns and demand may influence changes in management in Germany.

Table 26: Drivers for changes in land-use and soil management for sclerophyllous vegetation

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Nature and environments					
Climate change - Increased temperature	Spain	(Albaladejo et al., 2013)	Possibly change	Possible decrease	Possibly change
Climate change - Extreme weather	Spain	(Albaladejo et al., 2013)	Possibly change	Possible decrease	Possibly change
Socio-cultural context					
Changes in consumption patterns and demand	Germany	(Schrautzer et al., 2016)	Same	Same	Possibly worse

5.3.4 Transitional woodland/shrub

Transitional woodland/shrub is a subtype within shrub and/or herbaceous vegetation associations, which is described as, ´transitional bushy and herbaceous vegetation with occasional scattered trees, can represent woodland degradation, forest regeneration/recolonisation or natural succession´ (Kosztra et al., 2019). Table 27 summarises the drivers, which are from technology and management, nature and environment, demography, and socio-cultural context categories, found relevant for this land-use. Recognition of the need for efficient spatial planning strategies across all land uses - Management and planning can lead to decreased intensity and improved management in Portugal, while climate change effects, such as shifts in precipitation, temperature, and wind patterns, can also lead to changes. Migrations such as declining rural population and changes in consumption patterns and demand can similarly lead to decreased intensity.

Table 27: Drivers for changes in land-use and soil management for transitional woodland/shrub

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Recognition of the need for efficient spatial planning strategies across all land uses - Management and planning.	Portugal	(Sil et al., 2017)	Possibly change	Possibly decrease	Possibly improve
Nature and environments					
Climate change - Shift in precipitation, temperature, and wind patterns	Portugal	(Follmi et al., 2022)	Change	Possibly change	Possibly change
Demography					
Migration - Declining rural population	Portugal	(Carvalho-Santos et al., 2019)	Change	Decrease	Possibly change
Socio-cultural context					
Changes in consumption patterns and demand	Italy	(Bordoni et al., 2020)	Change	Decrease	Possibly improve

5.3.5 Beaches, dunes, sands

Beaches, dunes, and sands are a subtype within open spaces with little to no vegetation, which are described as ´Natural non-vegetated expanses of sand or pebble/gravel, in coastal or continental locations, like beaches, dunes, gravel pads; including beds of stream channels with torrential regime. Vegetation covers a maximum of 10% (Kosztra et al., 2019). Table 28 summarises the drivers, which are from nature and environment, and economy categories, found relevant for this land-use. Beaches and dunes everywhere are expected to be impacted by sea-level rise and tourism demand, with potential changes in use and intensity.

Table 28: Drivers for changes in land-use and soil management for beaches, dunes, and sands

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Nature and environments					
Climate change - sea level rise	Relevant everywhere	(Hinkel et al., 2013)	Change	Unsure	Unsure
Economy					
Increasing demand for tourism/recreational use	Relevant everywhere	(Hinkel et al., 2013)	Possibly change	Possibly increase	Possibly decrease

5.3.6 Inland wetlands (marshes, peatbogs)

Inland wetlands are a subtype within wetlands, which are described as ´Areas flooded or liable to flooding during the great part of the year by fresh, brackish or standing water with specific vegetation coverage made of low shrub, semi-ligneous or herbaceous species´ (Kosztra et al., 2019). Table 29 lists the driver, which is from the nature and environment category, found relevant for this land-use. Shifts in precipitation, temperature, and wind patterns are found to influence changes in land/use and management in inland wetlands, which include marshes and peatbogs.

Table 29: Drivers for changes in land-use and soil management for inland wetlands

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Nature and environments					
Climate change - Shift in precipitation, temperature, and wind patterns	Relevant everywhere	(Catania et al., 2022)	Possibly change	Same	Possibly change

5.3.7 Coastal wetlands

Coastal wetlands are a subtype within wetlands, which are described as ´Areas which are submerged by high tides at some stage of the annual tidal cycle. Includes salt meadows, facies of salt marsh grass meadows, transitional or not to other communities, vegetation occupying zones of varying salinity and humidity, sands and muds submerged for part of every tide, devoid of vascular plants, active or recently abandoned salt-extraction evaporation basins (Kosztra et al., 2019). Table 30 lists the driver, which is from the nature and environment category, found relevant for this land-use. Similar to beaches, dunes, and sands, coastal wetlands, particularly in the Baltic region, are expected to be influenced by the sea level rise, with changes in use which may result in increased intensity and change in management.

Table 30: Drivers for changes in land-use and soil management for coastal wetlands

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Nature and environments					
Climate change - sea level rise	Baltic region	(Schibalski et al., 2022)	Change	Possibly increase	Change

5.3.8 Mixed

Mixed natural areas refer to different land uses in nature and agriculture, mostly grassland and pasture, as well as agroforestry, which tends to have overlaps. Table 31 summarises the drivers, which are from technology and management, demography, and socio-cultural context categories, found relevant. Technology and management drivers, Adoption of Nature-based solutions and Sustainable practices and Recognition of the need for efficient spatial planning strategies across all land uses can potentially influence changes in use and management, and decrease intensity, specifically in Italy. Demography driver, migration related to the declining rural population, will influence changes and possibly abandonment of this land/use in Spain. Socio/cultural context driver, changes in consumption pattern and demand may change use and management in Europe, and decrease in intensity in Spain.

Table 31: Drivers for changes in land-use and soil management for mixed natural areas

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Adoption of Nature-based solutions and Sustainable practices	Relevant everywhere	(Fryer & Williams, 2021)	Possibly change	Possibly decrease	Possibly change
Recognition of the need for efficient spatial planning strategies across all land uses	Italy	(Assennato et al., 2020)	Possibly change	Possibly change	Possibly change
Demography					
Migration - Declining rural population	Spain	(Vázquez et al., 2020)	Change	Decrease	Change
Socio-cultural context					
Changes in consumption patterns and demand	Europe	(Polce et al., 2016)	Possibly change	Unsure	Unsure
	Spain	(Ries, 2010)	Possibly change	Possibly decrease	Possibly change

5.4 Soil and land pressures in Urban and industrial land-use

Urban industrial land-use in this study can be correlated to the land-use Class 1 Artificial surfaces according to the Corine Land Cover (CLC) classifications (Kosztra et al., 2019). Table 32 summarises the main types and subtypes according to CLC classification within this category. Although most urban studies did not differentiate between the types, but few studies could be linked to industrial or commercial units and public facilities, construction sites, and green urban areas.

Table 32: Urban and industrial land-use types and sub-types

Main type	Sub-type
Urban fabric	Continuous urban fabric
	Discontinuous urban fabric
Industrial, commercial and transport units	Industrial or commercial units and public facilities
	Road and rail networks and associated land
	Port areas
	Airports
Mine, dump and construction sites.	Mineral extraction sites
	Dump sites
	Construction sites
Artificial non-agricultural vegetated areas	Green urban areas
	Sport and leisure facilities

5.4.1 Industrial or commercial units and public facilities

Industrial or commercial units and public facilities are a sub-type within industrial or commercial and transportation units, which are described as, ´Buildings, other built-up structures and artificial surfaces (with concrete, asphalt, tarmacadam, or stabilised like e.g. beaten earth) occupy most of the area. It can also contain vegetation (most likely grass) or other non-sealed surfaces (Kosztra et al., 2019). Table 33 summarises the drivers, which are from technology and management, demography, and socio-cultural context categories, found relevant for this land-use. While current land management practices related to waste and pollution may lead to a decrease in intensity, advancements in tools and models for soil monitoring and land management, Waste and pollution may bring forward changes to the management of the land. Advancement in tools and models for soil monitoring and land management - Management and planning will similarly bring forward changes in use, intensity and management of industrial and commercial land. Socio-cultural context driver, increasing awareness and literacy of soil-based ecosystem services may influence how land is being used for the purpose of industrial, commercial, or public reasons.

Table 33: Drivers for changes in land-use and soil management for industrial and commercial units

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Advancement in tools and models for soil monitoring and land management - Management and planning	Europe	(Erős et al., 2023)	Change	Change	Change
Advancement in tools and models for soil monitoring and land management - Waste and pollution	EU	(EEA, 2022)	Same	Same	Change
Current land management practice - Waste and pollution	France	(Le Guern et al., 2018)	Same	Possibly decrease	Same
Socio-cultural context					
Increasing awareness and literacy of soil-based ecosystem services	Relevant everywhere	(Carla S. S. Ferreira et al., 2018)	Change	Same	Same

5.4.2 Construction sites

Construction sites are a subtype within mine, dump and construction sites, which are described as, ´Spaces under construction development, soil or bedrock excavations, earthworks´ (Kosztra et al., 2019). Table 34 lists the driver, which is from the technology and management category, found relevant for this land-use. Recognition of the need and progress towards standardisation of soil health indicators can potentially lead to changes in intensity and management of construction sites.

Table 34: Drivers for changes in land-use and soil management for construction sites

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Recognition of the need and progress towards standardisation of soil health indicators	Relevant everywhere	(Gómez-Sagasti et al., 2018)	Same	Change	Possibly change

5.4.3 Green urban areas

Green urban areas are a subtype within artificial non-agricultural vegetated areas, which are described as ´Areas with vegetation within or partly embraced by urban fabric. This class is assigned for urban greenery, which usually has a recreational or ornamental character and is usually accessible to the public (Kosztra et al., 2019). Table 35 summarises the drivers, which are from technology and management, and policy and institutional arrangements, found relevant for this land-use. Adoption of Nature-based solutions and Sustainable practices - Waste and pollution can potentially bring forward positive changes in management for the green urban areas. Policy and institutional arrangement drivers, Nature Restoration Law and Biodiversity strategy for 2030 also similarly bring changes in use and management for this type of land-use.

Table 35: Drivers for changes in land-use and soil management for green urban areas

Driver	Location	Citation	Land-use change	Intensity change	Management quality change
Technology and Management					
Adoption of Nature-based solutions and Sustainable practices - Waste and pollution	Relevant everywhere	(Malone et al., 2023)	Same	Same	Possibly improve
Policy and institutional arrangements					
EU - EU level strategies, agreements and conventions - Laws or regulations regarding conservation - Nature Restoration Law	EU	("COM(2022) 304 final," 2022)	Change	Same	Change
EU - EU level strategies, agreements and conventions - Laws or regulations regarding conservation - Biodiversity strategy for 2030	EU	(EU, 2021)	Change	Same	Change

6 Outlook for the interpretation, communication, and future steps of the typology of drivers for soil health

Following the footsteps of the rigorous meta-analysis process set in the M1, M11, and D3.1, this deliverable presents the final results and analysis of the metadata on the drivers of soil health across the EU. The results present a vast pool of data on soil health at local and European scales for different soil health objectives, identify categories, standardise the typology of drivers, and explore the changes it brings in soil and land-use across the EU. An immense collaborative effort by the WP3 partners has made this work possible. The data has been analysed to explore different aspects and interpretations. Work that has been done so far, together with some of the future opportunities, will be reflected on in this chapter. Throughout the collection and sorting of the data, various internal partner meetings and communication have taken place, as well as communication with other work packages in the SOLO project. Section 6.1 summarises the internal and external communication that has taken place and outlines the future opportunities. Section 6.2 presents the future implications of this analysis, and plans for future work related to this will be carried out.

The process of planning and implementing the meta-analysis, as well as the synthesis and analysis of the metadata, has been a collaborative effort among WP3 task leaders and partners, and frequent communication took place. All the internal communication has been recorded and the document stored and shared in the internal SOLO repository among all the other consortium partners. First in-person communication on the meta-analysis process took place in October 2023 during the SOLO consortium in Barcelona, where the WP3 leader presented the process to the consortium partners and stakeholders. An initial set of drivers and their association with different soil health objectives and location, following the meta-which was achieved after the analysis of the metadata, was presented in the SOLO partners consortium in Wageningen in May 2024. Before the in-person meeting at Wageningen, the driver's list, along with locations and citations, was separated according to the relevant soil health objectives and shared with the associated Think Tanks. Following the input from the Think Tanks, the initial metadata was structured and presented in D 3.1, which, apart from concluding the requirements of the WP3, also helps to support the development of the outlooks for WP2. The association of the drivers and soil health objectives also helped to guide and validate soil week events for all the SOLO partners as part of WP4. WP3 also plays a strong role in the regional nodes of WP4. The DPSIR framework is also appropriate for the first workshop, and WP3 leader provided technical support to the regional nodes leader on the application of the tool. WP3 also provided a list and visualisation of drivers relevant for the regional nodes locations, which was also used to support the first regional nodes workshop. WP3 has also established strong links with the overall synthesis of the outlooks as part of WP4. The themes of the drivers´ category have been adopted by the synthesis to structure the content. WP3 actively contributes to the synthesis of the outlooks, providing help with the content and visualisation. Collaboration within the project is also ongoing and will continue to shape up even if the timeline for this work package comes to an end. WP3 will continue to validate the soil weeks for all the partners. The support it provided for the regional nodes will be further explored. In collaboration with the regional nodes leaders, the drivers for these locations will be further explored to establish a regional exploration of the drivers and the potential changes they can bring. The initial concept and framework for this collaboration were presented in the SOLO consortium meeting at Evora in September 2025. The exploitation scope of this collaboration is expected to be part of the future WP4 deliverables and a journal publication.

To potentially have a greater impact and to realise the full potential of the sorted data, the sorted data is to be uploaded to Bonares' repository, a public data repository. A data in brief journal is published thereafter (Chowdhury et al.) to establish the scientific significance of the meta-analysis, also in work to broaden the communication and scope of the results. The data was subsequently uploaded to Zenodo. And the deliverable 3.1, once accepted, was also made available to the public. The results were also presented at the IUSS (International Union of Soil Science) soil congress in 2024 in Florence (link). To exploit the results presented in this report, several future publications are planned to explore the results of the meta-analysis. One paper is currently at work to present the synthesised typology of drivers with their association with soil health across the EU and beyond. The second potential journal publication will build on that and connect the drivers to the potential of changes it can bring across soil use and land management in future across the EU. Future scientific conference presentations would also take place to promote the output and further its exploitation.

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8 References

Abdalla, M., Hastings, A., Bell, M. J., Smith, J. U., Richards, M., Nilsson, M. B., Peichl, M., Löfvenius, M. O., Lund, M., Helfter, C., Nemitz, E., Sutton, M. A., Aurela, M., Lohila, A., Laurila, T., Dolman, A. J., Belelli-Marchesini, L., Pogson, M., Jones, E., . . . Smith, P. (2014). Simulation of CO2 and Attribution Analysis at Six European Peatland Sites Using the ECOSSE Model. Water, Air, & Soil Pollution, 225(11), 2182. https://doi.org/10.1007/s11270-014-2182-8

Albaladejo, J., Ortiz, R., Garcia-Franco, N., Navarro, A. R., Almagro, M., Pintado, J. G., & Martínez-Mena, M. (2013). Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain. Journal of Soils and Sediments, 13(2), 265-277. https://doi.org/10.1007/s11368-012-0617-7

Anestis, V., Bartzanas, T., & Kittas, C. (2015). Life cycle inventory analysis for the milk produced in a Greek commercial dairy farm - The link to Precision Livestock Farming. Precision Livestock Farming 2015 - Papers Presented at the 7th European Conference on Precision Livestock Farming, ECPLF 2015,

Archidona-Yuste, A., Wiegand, T., Eisenhauer, N., Cantalapiedra-Navarrete, C., Palomares-Rius, J. E., & Castillo, P. (2021). Agriculture causes homogenization of plant-feeding nematode communities at the regional scale [Article]. Journal of Applied Ecology, 58(12), 2881-2891. https://doi.org/10.1111/1365-2664.14025

Assennato, F., Di Leginio, M., D'Antona, M., Marinosci, I., Congedo, L., Riitano, N., Luise, A., & Munafò, M. (2020). Land degradation assessment for sustainable soil management. Italian Journal of Agronomy, 15(4), 299-305. https://doi.org/10.4081/ija.2020.1770

Bais-Moleman, A. L., Schulp, C. J. E., & Verburg, P. H. (2019). Assessing the environmental impacts of production- and consumption-side measures in sustainable agriculture intensification in the European Union [Article]. Geoderma, 338, 555-567. https://doi.org/10.1016/j.geoderma.2018.11.042

Barberá, G. G., Martínez-Garagarza, X., Martínez-Mena, M., & Castillo, V. M. (2019). Soil moisture dynamics alone does not explain differences in growth associated to organic amendment in a reforestation of a semiarid ecosystem. Catena, 180, 383-391. https://doi.org/10.1016/j.catena.2019.05.006

Beyer, C., Liebersbach, H., & Höper, H. (2015). Multiyear greenhouse gas flux measurements on a temperate fen soil used for cropland or grassland [Article]. Journal of Plant Nutrition and Soil Science, 178(1), 99-111. https://doi.org/10.1002/jpln.201300396

Bordoni, M., Cislaghi, A., Vercesi, A., Bischetti, G. B., & Meisina, C. (2020). Effects of plant roots on soil shear strength and shallow landslide proneness in an area of northern Italian Apennines. Bulletin of Engineering Geology and the Environment, 79(7), 3361-3381. https://doi.org/10.1007/s10064-020-01783-1

Buschmann, C., Röder, N., Berglund, K., Berglund, Ö., Lærke, P. E., Maddison, M., Mander, Ü., Myllys, M., Osterburg, B., & van den Akker, J. J. H. (2020). Perspectives on agriculturally used drained peat soils: Comparison of the socioeconomic and ecological business environments of six European regions [Article]. Land Use Policy, 90, Article 104181. https://doi.org/10.1016/j.landusepol.2019.104181

Cameira, M. R., Rolim, J., Valente, F., Faro, A., Dragosits, U., & Cordovil, C. M. D. S. (2019). Spatial distribution and uncertainties of nitrogen budgets for agriculture in the Tagus river basin in Portugal – Implications for effectiveness of mitigation measures [Article]. Land Use Policy, 84, 278-293. https://doi.org/10.1016/j.landusepol.2019.02.028

Carrer, D., Pique, G., Ferlicoq, M., Ceamanos, X., & Ceschia, E. (2018). What is the potential of cropland albedo management in the fight against global warming? A case study based on the use of cover crops [Article]. Environmental Research Letters, 13(4), Article 044030. https://doi.org/10.1088/1748-9326/aab650

Carvalho-Santos, C., Marcos, B., Nunes, J. P., Regos, A., Palazzi, E., Terzago, S., Monteiro, A. T., & Honrado, J. P. (2019). Hydrological Impacts of Large Fires and Future Climate: Modeling Approach Supported by Satellite Data. Remote Sensing, 11(23).

Catania, V., Bueno, R. S., Alduina, R., Grilli, E., La Mantia, T., Castaldi, S., & Quatrini, P. (2022). Soil microbial biomass and bacterial diversity in southern European regions vulnerable to desertification. Ecological Indicators, 145, 109725. https://doi.org/https://doi.org/10.1016/j.ecolind.2022.109725

Cerdà, A., Ackermann, O., Terol, E., & Rodrigo-Comino, J. (2019). Impact of farmland abandonment on water resources and soil conservation in citrus plantations in eastern Spain [Article]. Water (Switzerland), 11(4), Article 824. https://doi.org/10.3390/w11040824

Chowdhury, S., Paul, C., Hamidov, A., Bayer, L., Arndt, M., McPherson, J., & Helming, K. (2025). Developing a Generic DPSIR Framework for Land Use and Soil Management: A Systems Approach to Maximise Soil Health. European Journal of Soil Science, 76(6). https://doi.org/10.1111/ejss.70230

Chowdhury, S., von Post, M., Vallejo, R. R., Mora, K. N., Hultman, J., Pennanen, T., Lindroos, A. J., & Helming, K. (2024). Drivers of soil health across European Union - Data from the literature review. Data Brief, 57, 111064. https://doi.org/10.1016/j.dib.2024.111064

COM(2022) 304 final, 2022/0195 (2022).

Díaz de Otálora, X., Epelde, L., Arranz, J., Garbisu, C., Ruiz, R., & Mandaluniz, N. (2021). Regenerative rotational grazing management of dairy sheep increases springtime grass production and topsoil carbon storage [Article]. Ecological Indicators, 125, Article 107484. https://doi.org/10.1016/j.ecolind.2021.107484

Drewer, J., Dufossé, K., Skiba, U. M., & Gabrielle, B. (2016). Changes in isotopic signatures of soil carbon and CO2 respiration immediately and one year after Miscanthus removal [Article]. GCB Bioenergy, 8(1), 59-65. https://doi.org/10.1111/gcbb.12230

EEA. (2022). Progress in the management of contaminated sites in the EU. European environmental Agency (EEA). Retrieved 19 January from https://www.eea.europa.eu/en/analysis/indicators/progress-in-the-management-of?utm_source=EEASubscriptions&utm_medium=RSSFeeds&utm_campaign=Generic&activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366

Erős, T., Petrovszki, J., & Mórocz, A. (2023). Planning for sustainability: Historical data and remote sensing-based analyses aid landscape design in one of the largest remnant European floodplains. Landscape and Urban Planning, 238, 104837. https://doi.org/https://doi.org/10.1016/j.landurbplan.2023.104837

ESDAC, J.-. (2024). Glossary. Retrieved 29.05 from https://esdac.jrc.ec.europa.eu/resource-type/glossary

EU. (2021). EU Biodiversity Strategy for 2030 Bringing nature back into our lives.

Fagúndez, J. (2013). Heathlands confronting global change: drivers of biodiversity loss from past to future scenarios. Annals of Botany, 111(2), 151-172. https://doi.org/10.1093/aob/mcs257

Fernández-Guisuraga, J. M., Calvo, L., Ansola, G., Pinto, R., & Sáenz de Miera, L. E. (2022). The effect of sheep grazing abandonment on soil bacterial communities in productive mountain grasslands [Article]. Science of The Total Environment, 851, Article 158398. https://doi.org/10.1016/j.scitotenv.2022.158398

Ferreira, C. S. S., Keizer, J. J., Santos, L. M. B., Serpa, D., Silva, V., Cerqueira, M., Ferreira, A. J. D., & Abrantes, N. (2018). Runoff, sediment and nutrient exports from a Mediterranean vineyard under integrated production: An experiment at plot scale [Article]. Agriculture, Ecosystems and Environment, 256, 184-193. https://doi.org/10.1016/j.agee.2018.01.015

Ferreira, C. S. S., Walsh, R. P. D., & Ferreira, A. J. D. (2018). Degradation in urban areas. Current Opinion in Environmental Science & Health, 5, 19-25. https://doi.org/https://doi.org/10.1016/j.coesh.2018.04.001

Follmi, D., Baartman, J., Benali, A., & Nunes, J. P. (2022). How do large wildfires impact sediment redistribution over multiple decades? Earth Surface Processes and Landforms, 47(13), 3033-3050. https://doi.org/https://doi.org/10.1002/esp.5441

Fowler, D., Steadman, C. E., Stevenson, D., Coyle, M., Rees, R. M., Skiba, U. M., Sutton, M. A., Cape, J. N., Dore, A. J., Vieno, M., Simpson, D., Zaehle, S., Stocker, B. D., Rinaldi, M., Facchini, M. C., Flechard, C. R., Nemitz, E., Twigg, M., Erisman, J. W., . . . Galloway, J. N. (2015). Effects of global change during the 21st century onthe nitrogen cycle [Review]. Atmospheric Chemistry and Physics, 15(24), 13849-13893. https://doi.org/10.5194/acp-15-13849-2015

Früh-Müller, A., Bach, M., Breuer, L., Hotes, S., Koellner, T., Krippes, C., & Wolters, V. (2019). The use of agri-environmental measures to address environmental pressures in Germany: Spatial mismatches and options for improvement [Article]. Land Use Policy, 84, 347-362. https://doi.org/10.1016/j.landusepol.2018.10.049

Fryer, J., & Williams, I. D. (2021). Regional carbon stock assessment and the potential effects of land cover change. Science of The Total Environment, 775, 145815. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.145815

García-Ruiz, J. M. (2010). The effects of land uses on soil erosion in Spain: A review [Review]. Catena, 81(1), 1-11. https://doi.org/10.1016/j.catena.2010.01.001

Gómez-Sagasti, M. T., Hernández, A., Artetxe, U., Garbisu, C., & Becerril, J. M. (2018). How Valuable Are Organic Amendments as Tools for the Phytomanagement of Degraded Soils? The Knowns, Known Unknowns, and Unknowns [Article]. Frontiers in Sustainable Food Systems, 2, Article 68. https://doi.org/10.3389/fsufs.2018.00068

González-Rosado, M., Parras-Alcántara, L., Aguilera-Huertas, J., & Lozano-García, B. (2023). Land conversion impacts on soil macroaggregation, carbon sequestration and preservation in tree orchards located in Mediterranean environment (Spain) [Article]. Agriculture, Ecosystems and Environment, 354, Article 108557. https://doi.org/10.1016/j.agee.2023.108557

Hastings, A., Yeluripati, J., Hillier, J., & Smith, P. (2013). Biofuel Crops and Greenhouse Gases. In Biofuel Crop Sustainability (pp. 383-405). https://doi.org/10.1002/9781118635797.ch12

Hinkel, J., Nicholls, R. J., Tol, R. S. J., Wang, Z. B., Hamilton, J. M., Boot, G., Vafeidis, A. T., McFadden, L., Ganopolski, A., & Klein, R. J. T. (2013). A global analysis of erosion of sandy beaches and sea-level rise: An application of DIVA. Global and Planetary Change, 111, 150-158. https://doi.org/https://doi.org/10.1016/j.gloplacha.2013.09.002

Huusko, K., Tarvainen, O., Saravesi, K., Pennanen, T., Fritze, H., Kubin, E., & Markkola, A. (2015). Short-term impacts of energy wood harvesting on ectomycorrhizal fungal communities of Norway spruce saplings. ISME J, 9(3), 581-591. https://doi.org/10.1038/ismej.2014.154

Jones, G. V. (2016). Grapevines in a changing environment: A global perspective. In Grapevine in a Changing Environment: A Molecular and Ecophysiological Perspective (pp. 1-17). https://doi.org/10.1002/9781118735985.ch1

Kath, J., Le Brocque, A. F., Reardon-Smith, K., & Apan, A. (2019). Remotely sensed agricultural grassland productivity responses to land use and hydro-climatic drivers under extreme drought and rainfall [Article]. Agricultural and Forest Meteorology, 268, 11-22. https://doi.org/10.1016/j.agrformet.2019.01.007

Kim, S., Axelsson, E. P., Girona, M. M., & Senior, J. K. (2021). Continuous-cover forestry maintains soil fungal communities in Norway spruce dominated boreal forests. Forest

Ecology and Management, 480, 118659. https://doi.org/https://doi.org/10.1016/j.foreco.2020.118659

Kolasa-Więcek, A. (2015). Modelling of GHGs in livestock farms and its significance. In Climate Change Impact on Livestock: Adaptation and Mitigation (pp. 347-355). https://doi.org/10.1007/978-81-322-2265-1_21

Korboulewsky, N., Perez, G., & Chauvat, M. (2016). How tree diversity affects soil fauna diversity: A review. Soil Biology and Biochemistry, 94, 94-106. https://doi.org/10.1016/j.soilbio.2015.11.024

Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2019). Updated CLC illustrated nomenclature guidelines.

Kourgialas, N. N. (2021). A critical review of water resources in Greece: The key role of agricultural adaptation to climate-water effects [Review]. Science of The Total Environment, 775, Article 145857. https://doi.org/10.1016/j.scitotenv.2021.145857

Le Guern, C., Baudouin, V., Sauvaget, B., Delayre, M., & Conil, P. (2018). A typology of anthropogenic deposits as a tool for modeling urban subsoil geochemistry: example of the Ile de Nantes (France). Journal of Soils and Sediments, 18(2), 373-379. https://doi.org/10.1007/s11368-016-1594-z

Lupp, G., Steinhäußer, R., Bastian, O., & Syrbe, R. U. (2015). Impacts of increasing bioenergy use on ecosystem services on nature and society exemplified in the German district of Görlitz [Article]. Biomass and Bioenergy, 83, 131-140. https://doi.org/10.1016/j.biombioe.2015.09.006

Malone, Z., Berhe, A. A., & Ryals, R. (2023). Impacts of organic matter amendments on urban soil carbon and soil quality: A meta-analysis. Journal of Cleaner Production, 419, 138148. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.138148

Marques, M. J., Bienes, R., Cuadrado, J., Ruiz-Colmenero, M., Barbero-Sierra, C., & Velasco, A. (2015). Analysing Perceptions Attitudes and Responses of Winegrowers about Sustainable Land Management in Central Spain [Article]. Land Degradation and Development, 26(5), 458-467. https://doi.org/10.1002/ldr.2355

Martínez-Cortijo, J., & Ruiz-Canales, A. (2018). Effect of heavy metals on rice irrigated fields with waste water in high pH Mediterranean soils: The particular case of the Valencia area in Spain [Article]. Agricultural Water Management, 210, 108-123. https://doi.org/10.1016/j.agwat.2018.07.037

Meersmans, J., Arrouays, D., Van Rompaey, A. J. J., Pagé, C., De Baets, S., & Quine, T. A. (2016). Future C loss in mid-latitude mineral soils: climate change exceeds land use mitigation potential in France. Scientific Reports, 6(1), 35798. https://doi.org/10.1038/srep35798

Norris, J., Matzdorf, B., Barghusen, R., Schulze, C., & van Gorcum, B. (2021). Viewpoints on cooperative peatland management: Expectations and motives of dutch farmers [Article]. Land, 10(12), Article 1326. https://doi.org/10.3390/land10121326

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervas, J., Jones, A., & Montanarella, L. (2022). European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies. European Journal of Soil Science, 73(6), e13315. https://doi.org/https://doi.org/10.1111/ejss.13315

Pardo, G., Martin-Garcia, I., Arco, A., Yañez-Ruiz, D. R., Moral, R., & Del Prado, A. (2016). Greenhouse-gas mitigation potential of agro-industrial by-products in the diet of dairy goats in Spain: A life-cycle perspective. Animal Production Science, Parras-Alcántara, L., Martín-Carrillo, M., & Lozano-García, B. (2013). Impacts of land use change in soil carbon and nitrogen in a Mediterranean agricultural area (Southern Spain) [Article]. Solid Earth, 4(1), 167-177. https://doi.org/10.5194/se-4-167-2013

Pereira, P., Barceló, D., & Panagos, P. (2020). Soil and water threats in a changing environment [Note]. Environmental Research, 186, Article 109501. https://doi.org/10.1016/j.envres.2020.109501

Piirainen, S., Finér, L., Mannerkoski, H., & Starr, M. (2007). Carbon, nitrogen and phosphorus leaching after site preparation at a boreal forest clear-cut area. Forest Ecology and Management, 243(1), 10-18. https://doi.org/https://doi.org/10.1016/j.foreco.2007.01.053

Polce, C., Maes, J., Brander, L., Cescatti, A., Baranzelli, C., Lavalle, C., & Zulian, G. (2016). Global change impacts on ecosystem services: a spatially explicit assessment for Europe [10.3897/oneeco.1.e9990]. One Ecosystem, 1, e9990. https://doi.org/10.3897/oneeco.1.e9990

Renwick, A., Jansson, T., Verburg, P. H., Revoredo-Giha, C., Britz, W., Gocht, A., & McCracken, D. (2013). Policy reform and agricultural land abandonment in the EU [Article]. Land Use Policy, 30(1), 446-457. https://doi.org/10.1016/j.landusepol.2012.04.005

Ries, J. B. (2010). Methodologies for soil erosion and land degradation assessment in mediterranean-type ecosystems. Land Degradation & Development, 21(2), 171-187. https://doi.org/https://doi.org/10.1002/ldr.943

Robinson, D. T., Murray-Rust, D., Rieser, V., Milicic, V., & Rounsevell, M. (2012). Modelling the impacts of land system dynamics on human well-being: Using an agent-based approach to cope with data limitations in Koper, Slovenia [Article]. Computers, Environment and Urban Systems, 36(2), 164-176. https://doi.org/10.1016/j.compenvurbsys.2011.10.002

Rodríguez, A., Iglesias, I., & de la Torre, A. (2022). Prioritisation tool for targeting the monitoring of veterinary pharmaceuticals in soils at a national level: The case of Spain. European Journal of Soil Science,

Saget, S., Costa, M., Barilli, E., Wilton de Vasconcelos, M., Santos, C. S., Styles, D., & Williams, M. (2020). Substituting wheat with chickpea flour in pasta production delivers more nutrition at a lower environmental cost [Article]. Sustainable Production and Consumption, 24, 26-38. https://doi.org/10.1016/j.spc.2020.06.012

Schibalski, A., Kleyer, M., Maier, M., & Schröder, B. (2022). Spatiotemporally explicit prediction of future ecosystem service provisioning in response to climate change, sea level rise, and adaptation strategies. Ecosystem Services, 54, 101414. https://doi.org/https://doi.org/10.1016/j.ecoser.2022.101414

Schrautzer, J., Breuer, V., Holsten, B., Jensen, K., & Rasran, L. (2016). Long-term effects of large-scale grazing on the vegetation of a rewetted river valley. Agriculture, Ecosystems & Environment, 216, 207-215. https://doi.org/https://doi.org/10.1016/j.agee.2015.09.036

Schultz, H. R., & Stoll, M. (2010). Some critical issues in environmental physiology of grapevines: Future challenges and current limitations [Article]. Australian Journal of Grape and Wine Research, 16(SUPPL. 1), 4-24. https://doi.org/10.1111/j.1755-0238.2009.00074.x

Serra, P., Giuntoli, J., Agostini, A., Colauzzi, M., & Amaducci, S. (2017). Coupling sorghum biomass and wheat straw to minimise the environmental impact of bioenergy production [Article]. Journal of Cleaner Production, 154, 242-254. https://doi.org/10.1016/j.jclepro.2017.03.208

Sil, Â., Fonseca, F., Gonçalves, J., Honrado, J., Marta-Pedroso, C., Alonso, J., Ramos, M., & Azevedo, J. C. (2017). Analysing carbon sequestration and storage dynamics in a changing mountain landscape in Portugal: insights for management and planning. International Journal of Biodiversity Science, Ecosystem Services & Management, 13(2), 82-104. https://doi.org/10.1080/21513732.2017.1297331

Smerald, A., Fuchs, K., Kraus, D., Butterbach-Bahl, K., & Scheer, C. (2022). Significant Global Yield-Gap Closing Is Possible Without Increasing the Intensity of Environmentally Harmful Nitrogen Losses [Article]. Frontiers in Sustainable Food Systems, 6, Article 736394. https://doi.org/10.3389/fsufs.2022.736394

Smolander, A., Törmänen, T., Kitunen, V., & Lindroos, A.-J. (2019). Dynamics of soil nitrogen cycling and losses under Norway spruce logging residues on a clear-cut. Forest Ecology and Management, 449. https://doi.org/10.1016/j.foreco.2019.06.041

Soil Monitoring Law, (2025).

Solinas, S., Tiloca, M. T., Deligios, P. A., Cossu, M., & Ledda, L. (2021). Carbon footprints and social carbon cost assessments in a perennial energy crop system: A comparison of fertilizer management practices in a Mediterranean area [Article]. Agricultural Systems, 186, Article 102989. https://doi.org/10.1016/j.agsy.2020.102989

Tomaz, A., Palma, P., Fialho, S., Lima, A., Alvarenga, P., Potes, M., Costa, M. J., & Salgado, R. (2020). Risk assessment of irrigation-related soil salinization and sodification in mediterranean areas [Article]. Water (Switzerland), 12(12), Article 3569. https://doi.org/10.3390/w12123569

Vázquez, E., Benito, M., Espejo, R., & Teutscherova, N. (2020). Response of soil properties and microbial indicators to land use change in an acid soil under Mediterranean conditions. Catena, 189, 104486. https://doi.org/https://doi.org/10.1016/j.catena.2020.104486

Vicente-Vicente, J. L., Gómez-Muñoz, B., Hinojosa-Centeno, M. B., Smith, P., & Garcia-Ruiz, R. (2017). Carbon saturation and assessment of soil organic carbon fractions in Mediterranean rainfed olive orchards under plant cover management [Article]. Agriculture, Ecosystems and Environment, 245, 135-146. https://doi.org/10.1016/j.agee.2017.05.020

Yang, B., Banerjee, S., Herzog, C., Ramírez, A. C., Dahlin, P., & van der Heijden, M. G. A. (2021). Impact of land use type and organic farming on the abundance, diversity, community composition and functional properties of soil nematode communities in vegetable farming [Article]. Agriculture, Ecosystems and Environment, 318, Article 107488. https://doi.org/10.1016/j.agee.2021.107488

Zander, P., Amjath-Babu, T. S., Preissel, S., Reckling, M., Bues, A., Schläfke, N., Kuhlman, T., Bachinger, J., Uthes, S., Stoddard, F., Murphy-Bokern, D., & Watson, C. (2016). Grain legume decline and potential recovery in European agriculture: a review [Review]. Agronomy for Sustainable Development, 36(2), Article 26. https://doi.org/10.1007/s13593-016-0365-y

Zistl-Schlingmann, M., Kwatcho Kengdo, S., Kiese, R., & Dannenmann, M. (2020). Management Intensity Controls Nitrogen-Use-Efficiency and Flows in Grasslands—A 15N Tracing Experiment. Agronomy, 10(4).

9 Appendix

Appendix 1

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Protocol for the analysis of drivers of Soil Health methodology

SOLO WP 3: Drivers of Soil Health across European Regions

Title	Protocol for the analysis of drivers of soil health methodology
Work package no:	WP 3
Deliverable Related no:	D 3.1 and D 3.2
Milestone no:	M1
Milestone	Protocol to conduct the analysis of drivers of soil health
Due date:	30-June- 2023
Submission date:	29-June- 2023
Dissemination level:	internal
Authors:	ZALF, ICLEI, LUKE, LUND, LEITAT
Version:	V4.0

Versioning and contribution history

VERSION	DATE	AUTHOR	NOTES
1,0	01.06.2023	Shaswati Chowdhury, Keerthi Bandru, Katharina Helming, ZALF	First draft communicated with partners of WP3
2,0	16.06.2023	ZALF, ICLEI, LUKE, LUND, LEITAT	Edited draft
4,0	29.06.2023	ZALF, ICLEI, LUKE, LUND, LEITAT	Final version

1 Analysis of Drivers of Soil Health

The aim of Work Package 3 (WP3) in the SOLO project is to investigate the drivers of future changes in soil and land management, in order to identify and comprehend the emerging opportunities and challenges related to soil health. The objective of this protocol is to set a common procedure of driving force analysis to understand the determinants of future soil use and land management practices. This protocol includes a step-by-step guide for identifying and characterising future soil health drivers, as well as a set of criteria for evaluating their links to and potential relevance for soil and land management changes. The protocol will be implemented twice across four land use types: agriculture, forestry, natural areas, and urban and industrial areas (Figure 1). The task leaders are associated with the land uses: 3.2.1 (agriculture), 3.2.2 (forestry), 3.2.3 (urban and industrial), and 3.2.4 (nature). The analysis takes a regional approach to identify the thematic, regions specific challenges and potentials that allow the sustainable use, management, and protection of European soils. The analysis takes into consideration developments in finished or ongoing EU soil mission projects such as SMS and PREPSOIL. By taking a comprehensive and multi-dimensional approach to understanding soil health drivers, the SOLO project aims to generate insights and recommendations that can inform policy, practice, and research in this critical area. The driving force analysis outputs will feed into the think tanks in WP 2 for further analysis of the links between pressures (soil and land management changes), states (soil health parameters) and eventually impacts (ecosystem services).

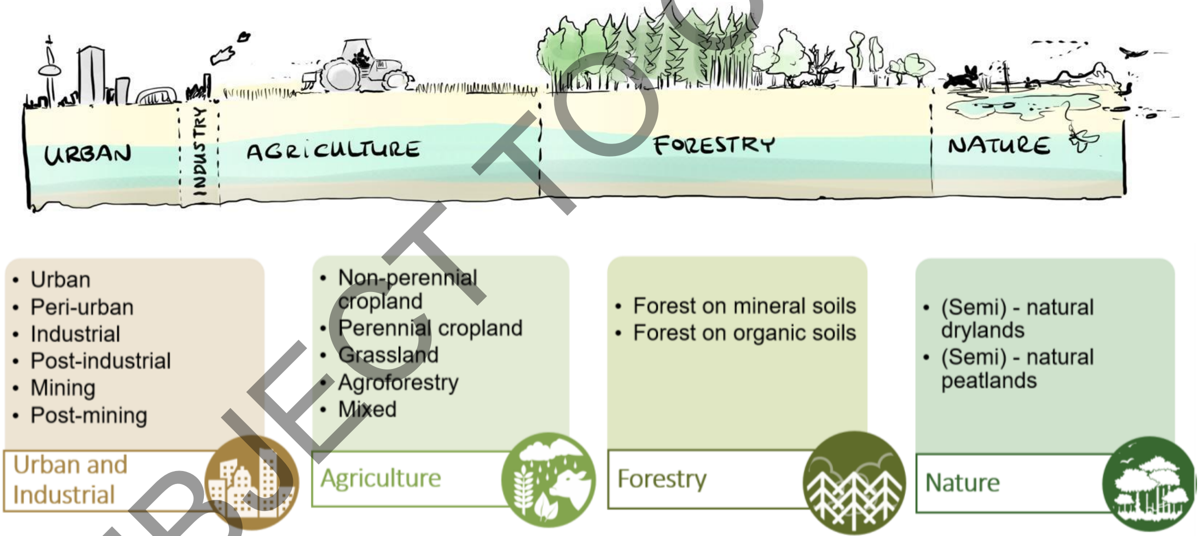


Figure 1 : Top. – Conceptualization of the land-use types. The length of the box is indicative for the percentage that that land-use covers Europe. All lengths added equals 100% (Drawings: Joost Fluitsma, sourced from SMS ontology report (https://www.soilmissionsupport.eu/news-2022/ontology), Bottom – Land use sub-types, adjusted with PREPSOIL land use categorisation.

For each land use type, the temporal and spatial dynamics of the identified drivers will be analysed, with a focus on understanding how they affect land managers' decision-making today and in the future. By analysing these dynamics, challenges and opportunities for soil health will be identified and understood. This will also provide crucial insights into the interactions between different drivers and the potential synergies and trade-offs between the drivers. The resulting typology of soil health drivers across land-use types and European environmental regions will facilitate the development of actionable roadmaps over the project's lifetime. This typology will be updated once during the lifetime of the project to ensure that the actionable roadmaps remain relevant and effective. These roadmaps will guide the implementation of policies and practices that promote soil health and overcome emerging barriers to improving land management.

2 Analytical framework

Driving force analysis of SOLO project (WP3) is built upon a comprehensive analytical framework which recognizes driving forces, pressures, state, impact, and response measures (DPSIR) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework (Figure 2) is a widely-used analytical tool for understanding the complex relationships between human activities and the environment (EEA 1999, Helming et al., 2018, Schjonning et al., 2015). The DPSIR framework can help to identify and analyse the different factors at various scales that influence soil health. The DIPSR framework has already been adopted in the ongoing national and EU projects (BonaRes, SMS, and PREPSOIL).

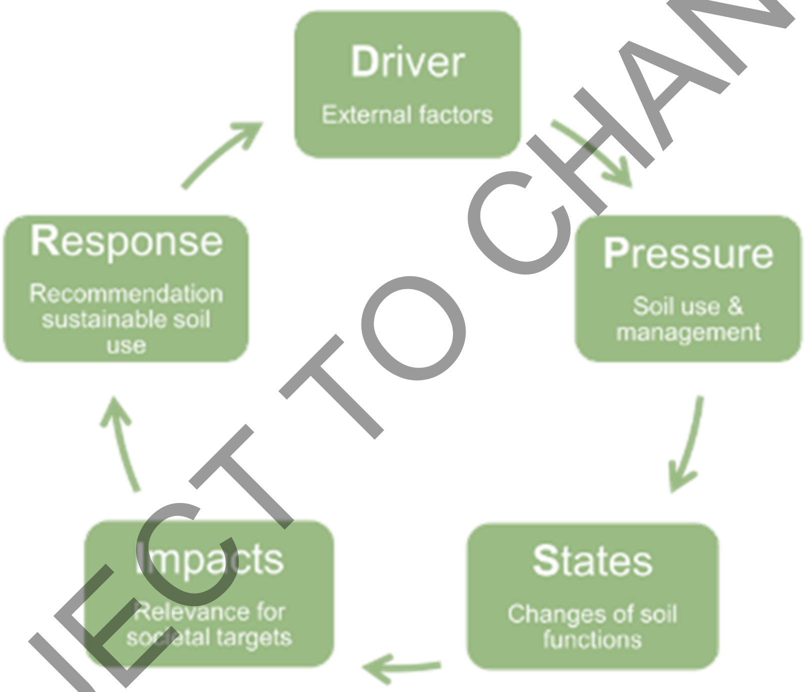


Figure 2: DPSIR Framework schematic for future soil and land use management (edited from Gabrielsen & Bosch (2003))

The drivers that affect soil health can be classified into various categories, including economic, social, institutional, and environmental factors. Economic factors such as market demand for crops, the availability and cost of inputs, and land values can have a significant impact on land use decisions and soil health. For example, if the demand for a particular crop is high, farmers may increase its production and intensify their use of inputs such as fertilizers, which can result in soil degradation. Social factors such as population growth, rural-urban migration, and changing lifestyles can also influence soil health. For instance, changes in consumer preferences for certain food items can lead to changes in land use and management practices that can impact soil health. Similarly, urbanization can lead to the conversion of agricultural land to sealed land, resulting in soil loss and degradation. Institutional factors such as policies, regulations, and land tenure arrangements can also play a significant role in determining the state of soil health. For example, subsidies for certain crops can incentivize farmers to adopt practices that may negatively impact soil health. Conversely, regulations that require the adoption of sustainable land management practices can promote soil health. Environmental factors such as climate change and soil erosion also affect soil health. Climate change can lead to changes in precipitation patterns and temperatures, which can affect soil moisture, nutrient availability and erosion vulnerability. Soil erosion can result in the loss of topsoil and nutrient-rich organic matter, leading to decreased soil health. Land use change can lead to the conversion of natural ecosystems to agricultural land, resulting in soil degradation and loss of biodiversity.

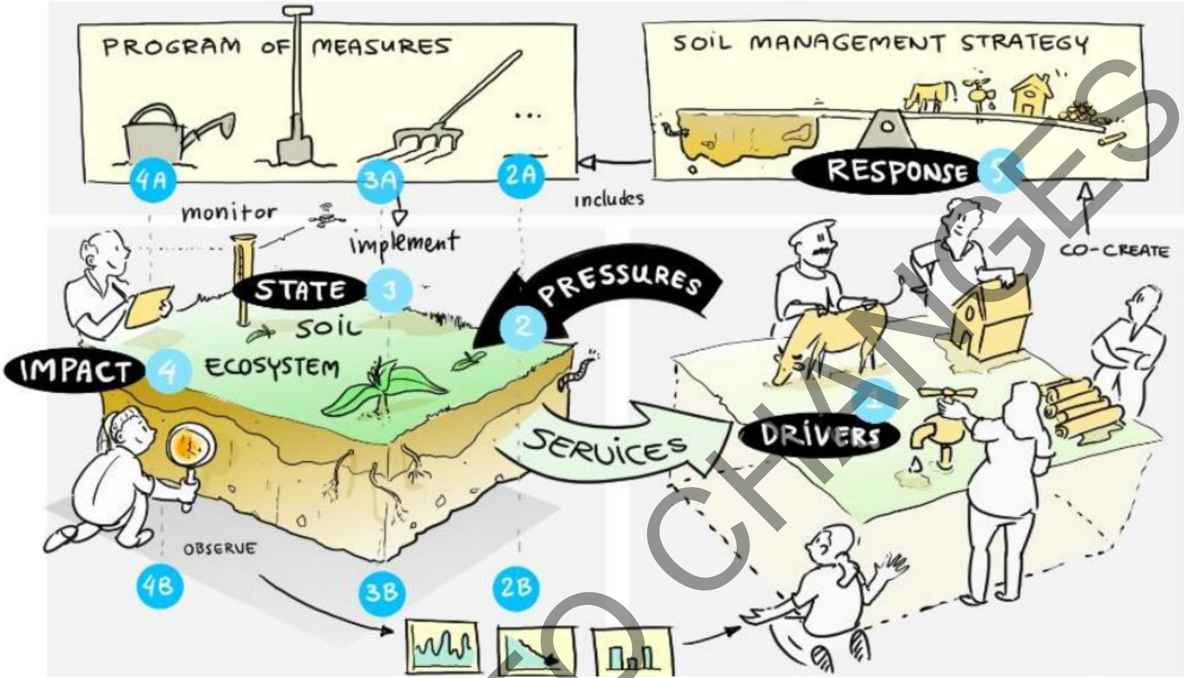


Figure 3: The DPSIR framework superimposed on the conceptual model for soil management (Drawings: Joost Fluitsma, sourced from SMS ontology report (https://www.soilmissionsupport.eu/news-2022/ontology))

These driving forces can lead to various pressures on soil health, such as land use change, land use intensity change, management change (Figure 3). The current state of soil health in Europe can vary widely depending on the specific region and soil properties and processes leading to soil functions and soil health. The impacts of soil degradation on soil related ecosystem services; human health, environmental health in Europe can be significant and far-reaching, affecting everything from food security to water quality to climate regulation. To address these issues, a range of responses such as institutional, policy, technology changes have been developed at both the national and EU levels. These include measures such as the Common Agricultural Policy, which provides funding for sustainable land management practices, as well as initiatives such as the EU Soil Framework Directive, which sets standards for soil protection and promotes sustainable soil management practices.

3 Methodology: Guidelines for the driving force analysis

The WP3 of the SOLO project aims to understand the drivers of soil health in Europe, including both internal and external factors that influence soil health at various spatial and temporal scales. A combination of meta-analysis and stakeholder consultation will be used to develop the protocol. Each task leader will be suggested to build their analysis on the successive steps outlined below. The outcomes from this analysis will be feed into the think tanks WP2 for developing the roadmaps for each EU soil mission objectives. It is envisioned that the discussion may generate new questions. The categorisation of drivers shall take into consideration of 8 objectives of the soil mission. The WP 2 will establish the think-tanks for each of the soil mission objectives. WP2 Think tanks will the take over and analyse where and under which conditions such management changes lead to soil health changes (using the soil threats as guiding principle). The task work is summarised in Table 1. The task includes three workshops, three milestones, and two deliverables.

Table 1 : Summary of SOLO WP3 activity

Date	Project month	Work shop	Mile-stone	Deliverable	Description
3/2023	4	W1			**Workshop 1:** together with stakeholders identify the types of drivers we will be analysing Workshop will be replaced by taking up and further analysing results on stakeholder inclusive soils needs analysis in 21 regions from PREPSOIL project
6/2023	7		M1		**Protocol** for the analysis of drivers for soil health = methodology
1/2024	14	W2			**Workshop 2:** discuss and validate preliminary results retrieved from desk research Workshop will be done in combination with the SOLO meeting in Barcelone Nov 23 (project month 12)
4/2024	17		M4-7		**Typology** and regional differentiation of key drivers of soil health for agriculture, forests, urban and industrial, natural areas
5/2024	18			D3.1	**Summary of the typology** and regional differentiation of key drivers of soil health across sectors
11/2024	24	W3			**Workshop 3:** revisit the previous results on driving forces re-validate priorities and relevancies
5/2025	30		M11		**Synthesis typology** of external drivers of soil health across land use types and European regions
11/2025	36			D3.2	**Final report** on a synthesis typology of external drivers of soil health across and use types and European regions

To achieve the task objectives, the task work is divided into three steps which are also further divided into sub-steps. The work breakdown structure is elaborated below:

- Step 1 (S1) – Typology of the drivers for future changes in soil and land use management
    - Sub-step 1 (S1.1) – Initial inventory and characterisation of drivers for different land uses with the meta-analysis
    - Sub-step 2 (S1.2) – Standardisation of the drivers across different land uses
    - Sub-step 3 (S1.3) – Identification and differentiation of the regional and general specificity of the drivers

- Step 2 (S2) - Drivers interactions and impacts on the soil and land use management over time
    - Sub-step 1 (S2.1) – Fixed scenario with EU climate targets - Timeline complying with the EU policy goals and climate targets and EU green deal targets 2030/2050
    - Sub-step 2 (S2.2) – Flexible scenario with SSPs - Scenario analysis with different shared socio-economic pathways (SSPs)

- Step 3 (S3) - Analysis of drivers and their dynamics for future changes in soil and land use management.

The work associated with the sub-steps and the associated time line for finishing is summarised in table 2.

The protocol, as part of the milestone M1, is due on June 2023. The protocol at this stage will include clear methodology to carry out the work for Step 1 (completion of which corroborates to the first deliverable D 3.1), and guideline to carry out the work of Step 2 and 3. Workshop 2 due on Nov 2023 will not only take place to validate work done in step 1 but also to fine-tune and agree on the methodology for Step 2 together with the SOLO consortium. This way, the utility of the outcomes of the driving forces analysis in WP3 will be optimised. Similarly, workshop 3 scheduled to take place on Nov 2024 would also help to fine-tune and agree upon the methods for Step 3 as well as validation and prioritisation of work done in step 2. Apart from the use in the think-tanks of the SOLO project (WP2) for R&I roadmap development, the output of WP3 is directly of great benefit for stakeholders, policymakers, researchers, and scientists working towards ensuring the future of healthy soils in Europe or in general. Therefore, other forms of publications, opinion, conference or peer reviewed papers, are also written and distributed to communicate the WP3 results. The timeline presented on table 2 attempts to make room where such writing collaboration can take place. To facilitate cooperation and collaboration among the partners, virtual meetings at regular intervention are planned (see table 2). The agenda of these meetings will depend on the coming milestone, deliverables, deadlines or writing for the papers.

Table 2 : WP 3 work outlook and timeline

Workshop 3: Revisit the previous results and revalidate priorities and relevance, update on the progress of work

Sync month: Virtual correspondence

Workshop 2: Discuss and validate preliminary results from S1 and S2

		2023								2024												2025											
		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S1	S1S1		M 1 Protocol for the analysis of drivers						P 1: Opinion paper – Drivers for future changes in land use			Deadline for S1	M 4-7 Typology	D 3.1 summary of the typology	P 2: Journal paper based on D 3.1				Deadline for S2							M 11 Synthesis typology			Deadline for S3	Final report writing		**D 3.2 Final report**	
	S1S2																																
	S1S3								PREPSOIL result integration																								
S2	S2S1																				P 3: Journal paper based on S2 results												
	S2S2																																
S3																																	

Jun 2023: Methodology of S1, guidelines for S2 and S3 **Nov 2023**: Methodology for S2 and update for S3 **Nov 2024:** Methodology for S3

4 Step 1 - Inventory of the Drivers for *future changes* in soil and land use management

The task leaders 3.2.1 (agriculture), 3.2.2 (forest), 3.2.3 (urban and industrial areas), and 3.2.4 (natural areas) (figure 1) will be required to provide a preliminary selection of critical drivers for future changes for each relevant land-use type. The drivers are to be selected according to their potential to motivate the following future changes:

- Changes in use – drivers of anticipated changes in land-use compared to the present such as differences in type of use (uniformation, diversification, or gentrification), degree of use (intensification, extensification, or degradation), etc.
- Changes in management – drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc.
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.).

Corresponding to the aforementioned characteristics, drivers of changes can encompass a range but not limited to, technology and management (such as digitalisation, machinery, and new technologies for recycling and re-use), nature and environment (including changes in soil biodiversity, climate change, resource depletion, water scarcity and quality), policy and institutional arrangements (such as the Common Agricultural Policy, the new EU soil health law, and land use policies at regional, national, and European levels), socio-cultural contexts (such as dietary preferences and educational levels), demography (including population size, age, and rural-urban linkages), and the economy (including land ownership, relative prices of commodities, energy prices, and market concentration).

4.1 Sub-step 1 (S1S1) – Initial inventory of drivers for different land uses with the meta-analysis

First sub-step of step 1 is to create the inventory of drivers of changes for different land-uses through a meta-analysis. The details for the meta-analysis is summarised on table 3. PRISMA protocol (Page et al., 2021) will be used to guide and synchronise the meta-analysis process (see appendix 8.2) Table 4 provides and initial set of drivers for all categorised land uses which is to be updated with:

- new drivers,
- short explanation of the drivers´ potential to motivate the future changes for the respective land use,
- brief exploration of the certain characteristics of the identified drivers.

The drivers list is to be updated by a literature review of both scientific (peer-reviewed or conference papers) and grey literature (policy documents, reports, amendments, etc.). An initial selection of studies have been compiled (see appendix 8.1) which can be helpful to start the process of expanding on the inventory of the drivers. Table 5 and 6 provides the format for the updated list of drivers and explanation. Both of this list is available as an automated Excel format as well.

Table 3 ***: Details of data collection for the meta-analysis***

Publication type:	Peer-review, think-tank reports, government publications, inventory reports, blog posts, scenarios and pathway studies, EU publications`
Time line:	2010-2023 and predictions up to 2100
Search engines	Google Scholar, Scopus, BASE, etc.
Key words	Select general and specific keywords related to land use types and drivers
Language	English and local language (regional specific)
Spatial	Regional to European level

Table 4 ***: List of drivers identified from the SOLO project proposal***

Land Use Type / Drivers Categories	Agriculture	Forest	Urban and Industrial	Natural
Technology and Management	• Digitalisation • Budget • Value chains • Changing farmers attitude • New and abandoned technology practices • Machinery • Agronomic and technological innovations • Novel negative emission solutions • Circular economies • New technologies for recycling and re-use	• Managed forest (Logging) • Non-Managed forest (nature conservation) • Circular production • Value chains • Forest fires • Deforestation • Invasive species • Tree species selection • Pollution	• Urban Sprawl • Novel approaches to fore integrating nature into urban environments through nature based solutions • Restoration • Pesticide free town initiatives	• Abandonment and rewilding • Drought • Land Use change
Nature and Environment	▪ Soil biodiversity ▪ Climate change ▪ Resource depletion ▪ Long-term contamination of soils ▪ Water scarcity and quality	• Climate change • Nitrogen deposition • Pathogens	• Climate change • Urban heat island effect • Flooding • Earth quakes	• Climate change
Policy and Institutional Arrangement	▪ CAP ▪ Price trends ▪ The new Soil health law ▪ Land use policies at regional, national and EU level ▪ Climate policies	International regulations and certifications	• Legal and regulatory constraints • Perverse incentives-adverse economic dynamics	• Regulation of protected areas • Policy – Biodiversity strategy • Sustainable pesticide use directive
Demography	• Population Size • Population age • Rural-Urban Linkages			
Socio-cultural contexts	▪ Dietary preferences ▪ Consumer demands for pesticide free agriculture, ▪ Educational levels Literacy			
Economy	▪ Land ownership ▪ Relative prices of commodities ▪ Energy prices ▪ Market concentration	• Economy • Trade		

*Table 5 : **Format for updated list of drivers for future with explanations (example is provided and highlighted)***

List of drivers for ´Insert land use type´		Source	Explanation
Categories	Individual drivers		
Technology and Management	Digitalisation (for land-use agriculture)	EC (2021)	Emerging digital technologies would lead to smart exploitation of ecological processes as well as smart management and monitoring of associated ecosystem services.
	Rows added or deleted if needed		
Nature and Environment			
	Rows added or deleted if needed		
Policy and Institutional Arrangement			
	Rows added or deleted if needed		
Demography			
	Rows added or deleted if needed		
Socio-cultural contexts			
	Rows added or deleted if needed		
Economy			
	Rows added or deleted if needed		

Table 6 : ***Format for updated list of drivers for future with brief exploration***

List of drivers for 'Insert land use'		Likely to affect			Ubiquity or specific setting in which it is likely to be relevant				Likely temporal dynamic (frequency)		Robustness of knowledge	
Categories	Individual drivers	Land use change	Land use intensity	Management quality	Environmental zones[1]	Land cover per Environmental zone[2]	Relevant soil health objectives[3]	Relevant stakeholders[4]	Short term	Long term	Well established	Uncertain
Technology and Management	Driver 1											
	Driver 2											
	Driver 3											

[1] Choose from the fifteen options, multiple options (1-13) can be combined together: 1. Alpine North, 2. Boreal, 3. Nemoral, 4. Atlantic North, 5. Alpine South, 6. Continental, 7. Atlantic, 8. Central, 9. Pannonian, 10. Lusitanian, 11. Med. Mountains, 12. Med. North, 13. Med. South., 14. Relevant everywhere. 15. Not sure. Classification based on Metzger, M. J., Shkaruba, A. D., Jongman, R. H. G., & Bunce, R. G. H. (2012). *Descriptions of the European Environmental Zones and Strata* (Alterra Report Issue.

[2] Choose from the following options, multiple options can be combined together (Corine landcover Level 3 identification number in parenthesis, see appendix 8.3). For Urban and Industrial: 1. Continuous urban fabric (111), 2. Discontinuous urban fabric (112), 3. Industrial or commercial units (121), 4. Road and rail network and associated land (122), 5. Port areas (123), 6. Airports (124), 7. Mineral extraction sites (131), 8. Dump sites (132), 9. Construction sites (133), 10. Green urban areas (141), 11. Sport and leisure facilities (142), 12. Relevant everywhere.

For Agriculture: 1. Non-irrigated arable land (211), 2. Permanently irrigated land (212), 3. Rice fields (213), 4. Vineyards (221), 5. Fruit trees and berry plantations (222), 7. Olive groves (223), 8. Pastures (231), 9. Annual crops associated with permanent crops (241), 10. Complex cultivation patterns (242), 11. Land principally occupied by agriculture, with significant areas of natural vegetation (243), 12. Agro-forestry areas (244), 13. Relevant everywhere. 14. Not sure.

For Forestry: 1. Broad-leaved forest (311), 2. Coniferous forest (312), 3. Mixed forest (313), 4. Relevant everywhere. 5. Not sure.

For Nature: 1. Natural grasslands (321), 2. Moors and heathland (322), 3. Sclerophyllous vegetation (323), 4. Transitional woodland-shrub (324), 5. Beaches, dunes, sands (331), 6. Bare rocks (332), 7. Sparsely vegetated areas (333), 8. Burnt areas (334), 9. Glaciers and perpetual snow (335), 10. Inland marshes (411), 11. Peat bogs (412), 12. Salt marshes (421), 13. Salines (422), 14. Intertidal flats (423), 15. Relevant everywhere. 16. Not sure.

Classification based on Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2019). *Updated CLC illustrated nomenclature guidelines*.

[3] Choose from the following seven options, multiple options can be combined together: 1. Land degradation, 2. Soil organic carbon stock, 3. Soil sealing, 4. Soil pollution 5. Soil erosion, 6. Soil structure 7. Soil literacy, 8. EU global footprint on soil, 9. All of them, 10. Not sure. Classification based on SOLO think tank objectives and EEA. (2022). *Soil monitoring in Europe — Indicators and thresholds for soil health assessments* (EEA report, Issue. , Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J. I., Paracchini, M. L., Abdul Malak, D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A. M., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A. I., . . . Santos-Martín, F. (2020). *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment* (EUR 30161 EN). (JRC Science for policy report, Issue. P. O. o. t. E. Union.

[4] State the relevant stakeholders associated with the driver. There´s no set list provided for this so the task leaders are asked to be as elaborate with their selection as possible. The idea is to collect the relevant stakeholders from all land uses and try to for a categorisation together.

	Driver n											
Nature and Environment	Driver 1											
	Driver 2											
	Driver 3											
	Driver n											
Policy and Institutional Arrangement	Driver 1											
	Driver 2											
	Driver 3											
	Driver n											
Demograp hy	Driver 1											
	Driver 2											
	Driver 3											
	Driver n											
Socio-cultural contexts	Driver 1											
	Driver 2											
	Driver 3											
	Driver n											
Economy	Driver 1											
	Driver 2											
	Driver 3											
	Driver n											

4.2 Sub-step 2 (S1S2) – Standardisation of the drivers across different land uses

Upon completion of the inventory of drivers by the respective task leaders, the second sub-step is to compare the list of drivers across the different land uses for similarities in description and language, and to create and agree on a standardised terminology for the drivers. This step is to be done in a virtual meeting (earliest in August, latest in October, 2023) among task leaders. For outreach and communication of the SOLO project activity and support the soil mission, the output of the workshop along with the results from sub-step 1 and 2 will be summarised in an opinion paper and published either as a conference paper or scientific communication paper.

4.3 Sub-step 3 (S1S3) – Identification and differentiation of the regional and general specificity of the drivers

The standardised set of drivers will be further analysed with for their region specific significance. The classification of 16 regions of Europe (Eurostat: Regions in Europe – 2022 interactive edition (europa.eu)) can be used to identify and differentiate the significance of drivers across different regions. This regional analysis would be further enriched with the drivers for soil needs generated by the PREPSOIL project. The PREPSOIL project generates a region specific list of drivers from the ongoing soil needs assessment from 21 regions in Europe. More details on the project can be found at https://prepsoil.eu/. Together with the task leaders, these drivers will be integrated in order to take up important, regionally specific drivers.

The outcome from this step 1 is the typology of the drivers for future changes in soil and land management in Europe, and brief description of how the drivers will motivate the future changes for the respective land uses and the associated challenges linked to the drivers. The initial outcome of this step will be communicated on the Workshop 2 that will take place in November 2023 in Barcelona. The outcome relates directly with the milestone M 4-7 Typology due on April 2024, and deliverable D 3.1 summary of the typology which is due on May 2024. Thus, the deadline for the step 1 is set to be March 2024. The task leaders will further identify the research gaps and develop an action plan to complete the remaining analysis in steps 2 and 3.

5 Step 2 - Drivers interactions and impacts on the soil and land use management over time

The Step 2 deals with analysing drivers over a timeline to understand their impact in achieving the EU climate/soil specific targets (sub-step 1 S2S1) and a prospective sustainable future (sub-step 2 S2S2). Following sub-sections provides an initial outlook of the boundary conditions for the timelines. The data collected in the Step 1 will assist with most of the exploration at this step and raw data is not expected to be collected unless required. The task leaders are expected to agree on a more detailed methodology for this step by October 2023 (finalised by November 2023) aligning with the tentative completion of the Step 1 (see Table 2).

5.1 Sub-step 1 (S2S1) – Timeline complying with the EU policy goals and targets

The first scenario analysis is a targeted impact analysis where the boundary conditions are set by the EU specific laws, regulations, guidelines or objectives and how they are impacted by the drivers over a timeline. Timeline is set on current, midterm (2030), and long term (2050). The objectives and associated targets regarding soil health and land use in EU for 2030 and 2050 are listed below. The objectives or target that is partially or entirely legally binding is listed in red.

EU soil strategy in 2021 ("COM(2021) 699 final," 2021) sets out with the vision to achieve good soil health across EU by 2050. The vision and objectives are detailed below:

This new vision for soil is anchored in the EU biodiversity strategy for 2030[14] and the Climate Adaptation Strategy[15]. This Soil Strategy therefore builds on and will significantly contribute to several of the objectives of the Green Deal and objectives prior to that:

Medium-term objectives 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 (Sustainable Development Goal 15.3) (UN, 2015)
- Significant areas of degraded and carbon-rich ecosystems, including soils, are restored ("COM(2020) 380 final," 2020).
- Achieve an EU net greenhouse gas removal of 310 million tonnes CO2 equivalent per year for the land use, land use change and forestry (LULUCF) sector ("COM(2021) 554 final," 2021).
- Reach good ecological and chemical status in surface waters and good chemical and quantitative status in groundwater by 2027 ("2000/60/EC," 2000).
- Reduce nutrient losses by at least 50%, the overall use and risk of chemical pesticides by 50% and the use of more hazardous pesticides by 50% by 2030 ("COM(2020) 381 final," 2020).
- Significant progress has been made in the remediation of contaminated sites ("COM(2020) 380 final," 2020).

Long-term objectives by 2050

- Reach no net land take ("DECISION No 1386/2013/EU," 2013; "COM(2011) 571 final," 2011).
- Soil pollution should be reduced to levels no longer considered harmful to human health and natural ecosystems and respect the boundaries our planet can cope with, thus creating a toxic-free environment ("COM(2021) 400 final," 2021).

- Achieve a climate-neutral Europe ("REGULATION (EU) 2021/1119," 2021) and, as the first step, aim to achieve land-based climate neutrality in the EU by 2035 ("COM(2021) 554 final," 2021)..
- Achieve for EU a climate-resilient society, fully adapted to the unavoidable impacts of climate change by 2050 ("COM(2021) 82 final," 2021).

The upcoming EU soil health law would give a set of clear targets till 2030 to achieve the goals set for 2050. The Mission Board for Soil health and food has been set up to guide the process and sets their own goal '**By 2030, at least 75% of all soils in each EU Member State are healthy, i.e. are able to provide essential ecosystem services'** (EC, 2020). The mission lines out the targets to achieve by 2030:

- **Land degradation** including desertification in drylands **is strongly reduced** and 50% of degraded land is restored moving beyond land degradation neutrality.
- High **soil organic carbon stocks** (e.g. in forests, permanent pastures, wetlands) **are conserved** and current carbon concentration losses on cultivated land (0.5% per year) are reversed to an **increase by 0.1-0.4% per year**. The area of peatlands losing carbon is reduced by 30-50%.
- **No net soil sealing** and an increased **re-use of urban soils** for urban development from the current rate of 13%-50%, to help stop the loss of productive land to urban development and meet the EU target of no net land take by 2050.
- **Reduced soil pollution**, with at least 25% area of EU farmland under **organic agriculture;** a further 5-25% of land with **reduced risk from eutrophication, pesticides, anti-microbials and other contaminants**, and a doubling of the rate of **restoration of polluted sites**.
- **Prevention of erosion** on 30-50% of land with unsustainable erosion rates.
- Improved **soil structure** to improve **habitat quality for soil biota** and crops including a 30 to 50% reduction in soils with high-density subsoils.
- 20-40% **reduced global footprint** of EU's food and timber imports on land degradation.

These outlines and set objectives for the two points in timeline, 2030 and 2050, to conduct a scenario analyses. The drivers and their relevance and impacts in accordance to the set targets in this two time points would be analysed.

5.2 ub-step 2 (S2S2) – Scenario analysis with different shared socio-economic pathways (SSPs)

The second scenario analysis is an exploratory analysis where the drivers' impacts are analysed according to different socio-economic pathways (SSPs). The SSPs to be adapted in this scenario analysis are based on the Eur-Agri SSPs (Mitter et al., 2019; Mitter et al., 2020) (Figure 4).

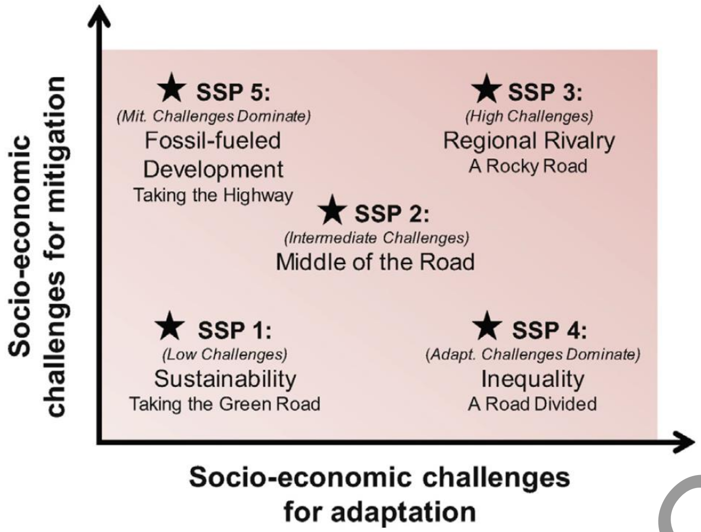


Figure 4 : The Eur-Agri SSPs (source : O'Neill et al. (2017))

6 Step 3 - Analysis of drivers and their dynamics for future changes in soil and land use management

The Step 3 deals with analysing and explore the drivers in various aspects to understand their dynamics and characteristics in detail. The exploration could include, but is not limited to, drivers impact individually and separately, locally and regionally, for one land use and across all land uses. The data collected in the Step 1 will assist with most of the exploration at this step and raw data is not expected to be collected unless required. The task leaders are expected to agree on a more specific outline for this step by October 2023, and a detailed methodology by November 2024 and aligning with the tentative completion of the Step 2 (see table 2).

One example of the dynamic assessment could be severity assessment.

Severity assessment: The task leaders will agree on a method (expert participatory assessment) to develop the hierarchy of drivers that impact the soil health in the different land use types. The list of drivers that are identified from the systematic review will be then analysed to agree on the drivers to be focused for each land use type/regions. The outcomes of the analysis shall develop the severity of selected drivers that affect the soil health. An example of such analysis is presented in the figure 5. The severity may be identified from the literature review and validated with the participatory expert workshops. The driver's impact on land improvement and degradation shall also be developed.

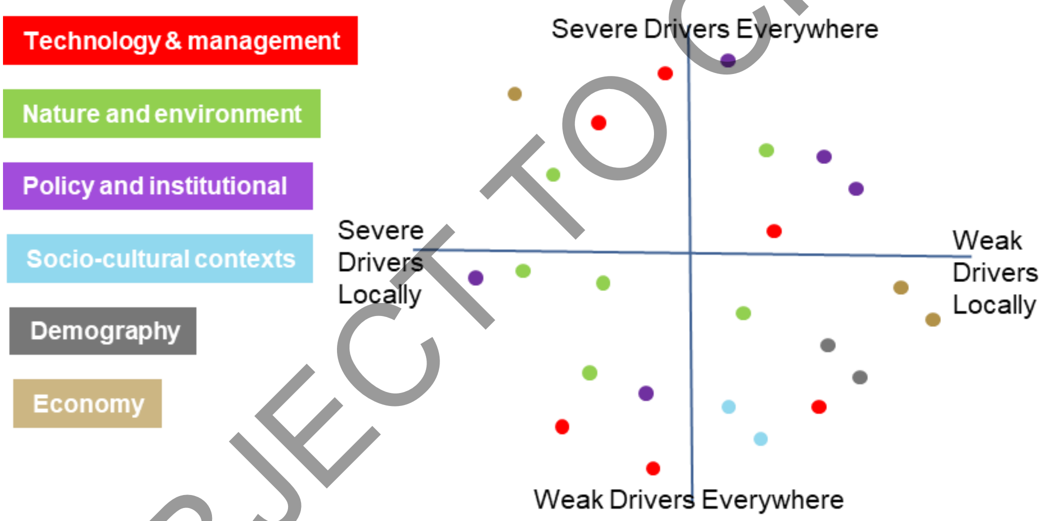


Figure 5: Example foresight of emerging soil health drivers

7 References

EEA Report, 1999. Environmental Indicators: Typology and Overview. https://www.eea.europa.eu/publications/TEC25

Gabrielsen, P. and Bosch, P. (2003) Environmental Indicators: Typology and Use in Reporting. Internal Working Paper, Copenhagen.

Helming, K., Daedlow, K., Paul, C., Techen, A.-K., Bartke, S., Bartkowski, B., Kaiser, D., Wollschläger, U., & Vogel, H.-J. (2018). Managing soil functions for a sustainable bioeconomy. Assessment framework and state of the Art. Land Degradation & Development 29(9), 3112-3126 https://doi.org/DOI: 10.1002/ldr.3066

O'Neill,B; Kriegler,E; Ebi, K.L; Kemp-Benedict, E; Riahi, K; Rothman, D.S; van Ruijven, B.J; van Vuuren, D.P; Birkmann, J; Kok, K; Levy, M; Solecki, W. (2017) The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century, Global Environmental Change, Volume 42, Pages 169-180, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2015.01.004.

7th EU Environment Action Programme, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013D1386 (2013).

EC. (2020). *Caring for soil is caring for life : ensure 75% of soils are healthy by 2030 for healthy food, people, nature and climate : interim report of the mission board for soil health and food*. European Commission Publications Office. https://doi.org/doi/10.2777/918775

EEA. (2022). *Soil monitoring in Europe — Indicators and thresholds for soil health assessments* (EEA report, Issue.

EU Biodiversity Strategy for 2030, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380 (2020).

EU Soil Strategy for 2030, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699 (2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

European Climate Law, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1119 (2021).

A Farm to Fork Strategy, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0381 (2020). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0381

Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A82%3AFIN (2021).

Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2019). *Updated CLC illustrated nomenclature guidelines*.

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J. I., Paracchini, M. L., Abdul Malak, D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A. M., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A. I., . . . Santos-Martín, F. (2020). *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment* (EUR 30161 EN). (JRC Science for policy report, Issue. P. O. o. t. E. Union.

Metzger, M. J., Shkaruba, A. D., Jongman, R. H. G., & Bunce, R. G. H. (2012). *Descriptions of the European Environmental Zones and Strata* (Alterra Report Issue.

Mitter, H., Techen, A. K., Sinabell, F., Helming, K., Kok, K., Priess, J. A., Schmid, E., Bodirsky, B. L., Holman, I., Lehtonen, H., Leip, A., Le Mouel, C., Mathijs, E., Mehdi, B., Michetti, M., Mittenzwei, K., Mora, O., Oygarden, L., Reidsma, P., . . . Schonhart, M. (2019). A protocol to develop Shared Socio-economic Pathways for European agriculture. *J Environ Manage*, *252*, 109701. https://doi.org/10.1016/j.jenvman.2019.109701

Mitter, H., Techen, A. K., Sinabell, F., Helming, K., Schmid, E., Bodirsky, B. L., Holman, I., Kok, K., Lehtonen, H., Leip, A., Le Mouel, C., Mathijs, E., Mehdi, B., Mittenzwei, K., Mora, O., Oistad, K., Oygarden, L., Priess, J. A., Reidsma, P., . . . Schonhart, M. (2020). Shared Socio-economic Pathways for European agriculture and food systems: The Eur-Agri-SSPs. *Glob Environ Change*, *65*, 102159. https://doi.org/10.1016/j.gloenvcha.2020.102159

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, *42*, 169-180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . Moher, D. (2021). The PRISMA 2020 statement: an updated

guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71
Pathway to a Healthy Planet for All

EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400 (2021).
Proposal for a revision of the LULUCF Regulation, 2021/0201 (COD) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0554 (2021).
Roadmap to a Resource Efficient Europe, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52011DC0571 (2011).
UN. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. Paris: United Nations General Assembly
Water Framework Directive https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060 (2000).

8 Appendix

8.1 Literature list

Strauss et al. (2023) Sustainable soil management measures: a synthesis of stakeholder recommendations Agronomy for Sustainable Development (2023) 43:17 https://doi.org/10.1007/s13593-022-00864-7

Techen et al. (2020) Soil research challenges in response to emerging agricultural soil management practices. Advances in Agronomy, Volume 161, ISSN 0065-2113 https://doi.org/10.1016/bs.agron.2020.01.002

Techen and Helming (2017) Pressures on soil functions from soil management in Germany. A foresight review, Agronomy for Sustainable Development (2017) 37: 64 https://doi.org/10.1007/s13593-017-0473-3

van Vilet et al. (2015) Manifestations and underlying drivers of agricultural land use change in Europe, Landscape and Urban Planning 133 (2015) 24–36, http://dx.doi.org/10.1016/j.landurbplan.2014.09.001

Dicks et al. (2018). *Knowledge synthesis for environmental decisions: an evaluation of existing methods, and guidance for their selection, use and development – a report from the EKLIPSE project*

Lapola et al. (2023) Analytical review: The drivers and impacts of Amazon forest degradation, Science Jan 27;379 (6630):eabp8622, doi:10.1126/science.abp8622

Rodríguez et al. (2022). Conservation Agriculture as a Sustainable System for Soil Health: A Review. Soil Syst. **2022**, 6, 87. https://doi.org/10.3390/soilsystems6040087

Gutzler et al. (2014) Agricultural land use changes – a scenario-based sustainability impact assessment for Brandenburg, Germany, Ecological Indicators 48 (2015) 505–517, http://dx.doi.org/10.1016/j.ecolind.2014.09.004

European Commission (2023), Drivers for food safety. Brussels, 4.1.2023 SWD (2023) 4 final

European Commission (2021), Mission Area: Soil Health and Food. Foresight on Demand Brief in Support of the Horizon Europe Mission Board, ISBN 978-92-76-41532-9 doi:10.2777/038626

Mitter et al (2020). Shared Socio-economic Pathways for European agriculture and food systems: The Eur-Agri-SSPs, Global Environmental Change 65 (2020) 102159, https://doi.org/10.1016/j.gloenvcha.2020.102159

Mitter et al. (2019). A protocol to develop Shared Socio-economic Pathways for European agriculture, Journal of Environmental Management 252 (2019) 109701, https://doi.org/10.1016/j.jenvman.2019.109701

IPBES (2019). The IPBES Assessment Report On Land Degradation and Restoration, ISBN No: 978-3-947851-09-6

Nicholas et al. (2018). *Direct and indirect drivers of land degradation and restoration.* (2018) 198 p.-314 p. pages http://hdl.handle.net/2078.1/207386

Smith et al. (2016). Global change pressures on soils from land use and management, Global Change Biology (2016) 22, 1008–1028, doi: 10.1111/gcb.13068

Radwan et al. (2021). Global land cover trajectories and transitions, Scientific Reports | (2021) 11:12814 | https://doi.org/10.1038/s41598-021-92256-2

United Nations Convention to Combat Desertification, 2022. The Global Land Outlook, second edition. UNCCD, Bonn.ISBN: 978-92-95118-53-9 eISBN: 978-92-95118-52-2

SEPA (2012). SWEDISH ENVIRONMENTAL PROTECTION AGENCY REPORT 6505, Land management meeting several environmental objectives, ISBN 978-91-620-6505-8, ISSN 0282-7298

Struck et al (2018). Simulating and delineating future land change trajectories across Europe, Reg Environ Change (2018) 18:733–749, https://doi.org/10.1007/s10113-015-0876-0

Virto et al. (2015). Soil Degradation and Soil Quality in Western Europe: Current Situation and Future Perspectives, *Sustainability* 2015, *7*, 313-365; doi:10.3390/su7010313

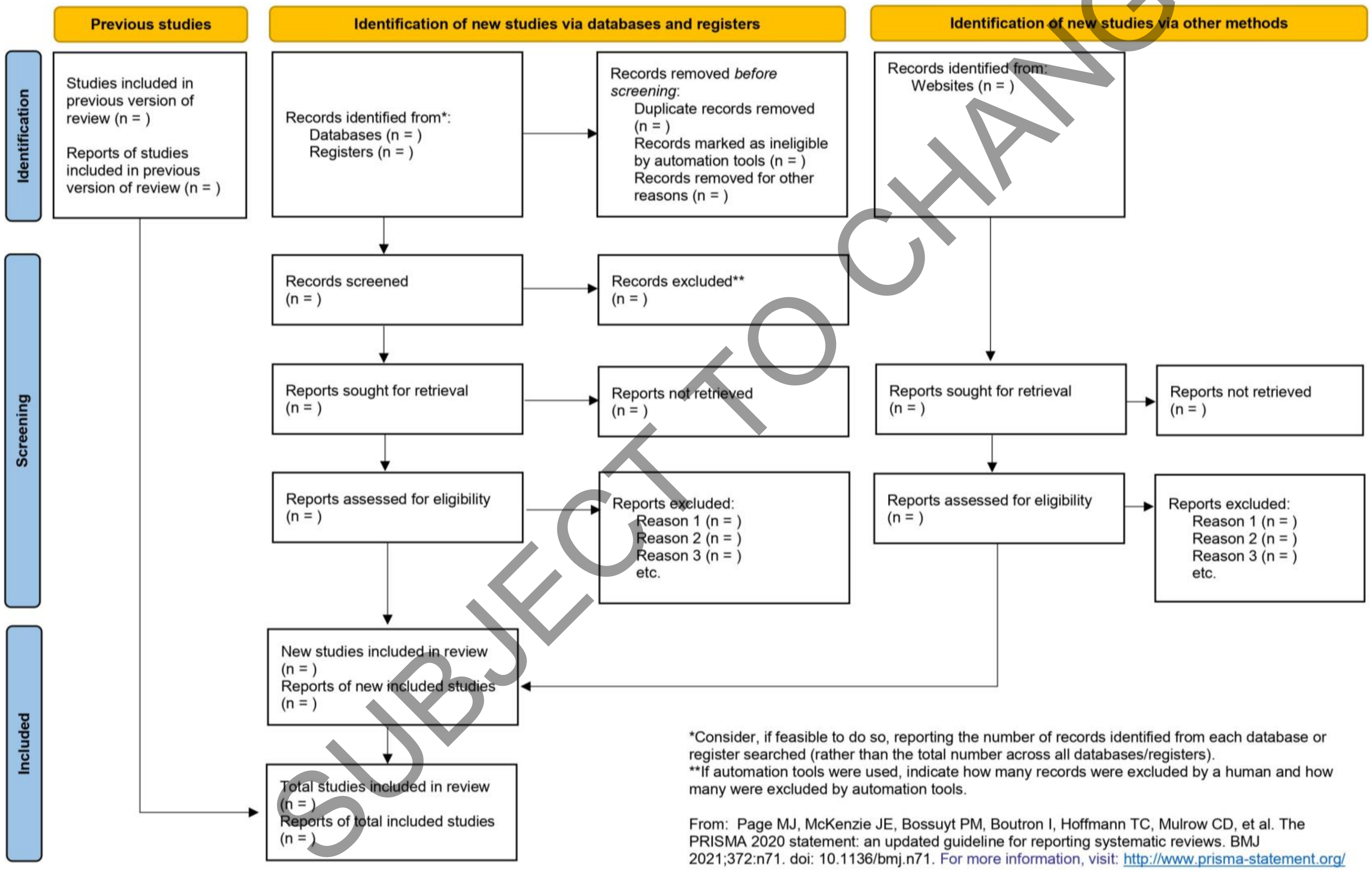
EEA (2016). Soil resource efficiency in urbanised areas - Analytical framework and implications for governance, ISSN 1977-8449

Davis et al. (2015), The global land rush and climate change, *Earth's Future*, *3*, 298–311, doi:10.1002/2014EF000281

8.2 PRISMA protocol

(The editable doc file is shared separately)

PRISMA 2020 flow diagram for updated systematic reviews which included searches of databases, registers and other sources



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

8.3 CLC land cover classification

Land cover classification (Kosztra et al., 2019)

Urban and industrial areas

- Continuous urban fabric
- Discontinuous urban fabric
- Industrial or commercial units
- Road and rail network and associated land
- Port areas
- Airports
- Mineral extraction sites
- Dump sites
- Construction sites
- Green urban areas
- Sport and leisure facilities

Agriculture

- Non-irrigated arable land
- Permanently irrigated land
- Rice fields
- Vineyards
- Fruit trees and berry plantations
- Olive groves
- Pastures
- Annual crops associated with permanent crops
- Complex cultivation patterns
- Land principally occupied by agriculture, with significant areas of natural vegetation
- Agro-forestry areas

Forestry

- Broad-leaved forest
- Coniferous forest
- Mixed forest

Nature

- Natural grasslands
- Moors and heathland
- Sclerophyllous vegetation
- Transitional woodland-shrub
- Beaches, dunes, sands
- Bare rocks
- Sparsely vegetated areas
- Burnt areas
- Glaciers and perpetual snow
- Inland marshes
- Peat bogs
- Salt marshes
- Salines
- Intertidal flats
- Water courses

- Water bodies
- Coastal lagoons
- Estuaries
- Sea and ocean

NODATA

Appendix 2

SOLO

Soils for Europe

Funded by the European Union

Typology of Drivers of Soil Health across European Union

Deliverable 3.1

10 June 2024

Shaswati Chowdhury, Maria von Post, Jenni Hultman, Roger Roca Vallejo, Karen Naciph Mora, Katharina Helming

SOLO
Soils for Europe

Funded by the European Union

Prepared under contract from the European Commission

Grant agreement No. 101091115
Horizon Europe Research and Innovation and other actions to support the implementation of a mission in the area of Soil health and Food

Project acronym:	**SOLO**
Project full title:	Soils for Europe
Start of the project:	December 2022
Duration:	5 years
Project coordinator:	Dr. Carlos António Guerra
Deliverable title:	Summary of the typology and regional differentiation of key drivers of soil health across sectors
Deliverable n°:	D3.1
Nature of the deliverable:	Report
Dissemination level:	Public
WP responsible:	WP3
Lead beneficiary:	Leibniz Centre for Agricultural Landscape Research (ZALF)
Citation:	Chowdhury, S., von Post, M., Vallejo, R.R., Mora, K. N., Helming. K. (2024). *Typology of Drivers of Soil Health across European* Union. Deliverable D3.1 EU Horizon 2020.
Due date of deliverable:	Month 18
Actual submission date:	Month 19

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Version	Status	Date	Authors and contributors
1.0	First Draft	01.04.2024	**Data curation:** Agriculture – Shaswati Chowdhury, ZALF Forest – Jenni Hultman, Taina Pennanen, Antti-Jussi Lindroos, LUKE Urban – Roger Roca Vallejo, Karen Naciph Mora, ICLEI Nature – Maria von Post, LU **Compilation and text:** Shaswati Chowdhury, ZALF
2.0	Draft for revision	30.05.2024	Shaswati Chowdhury ZALF
3.0	Final version	10.06.2024	Shaswati Chowdhury Katharina Helming ZALF Maria von Post LU Jenni Hultman LUKE Roger Roca Vallejo Karen Naciph Mora ICLEI
4.0	Revised version	11.10.2024	Shaswati Chowdhury Katharina Helming ZALF

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1 Introduction - Analysis of Drivers of Soil Health and the analytical framework

The aim of Work Package 3 (WP3) in the SOLO project is to investigate the drivers of future changes in soil and land management, in order to identify and comprehend the emerging opportunities and challenges related to soil health. To help govern the work of WP3, certain milestones, workshops and deliverables are put in place. The task includes three workshops, six milestones, and two deliverables. This is the first of the two deliverables, Deliverable 3.1 that provides in simple terms, a typology of drivers that impacts the future use and management of soil and land in the EU. The work process for this deliverable is set by the protocol developed as part of the milestone M1 (available as appendix 1) which was submitted in June 2023. An extensive meta-analysis is carried out to develop the typology of drivers, where they are located, and which soli health objectives they are impacting. The results of the outcomes from this analysis is planned to feed into the other work packages to support the development of the co-creation and knowledge developing platforms for each of the eight EU soil mission objectives (soil erosion, land degradation, soil structure, soil sealing, soil organic carbon, soil literacy, soil pollution, and EU global footprint on soil) and with the addition of soil biodiversity. The driving force analysis in the SOLO project (WP3) is built upon a comprehensive analytical framework which recognizes driving forces, pressures, state, impact, and response measures (DPSIR) as fundamental components of soil health. A scoping literature review is conducted to identify the drivers which will further feed into the analysis of the links between pressures (changes in soil and land management), and states (soil health objectives) and the respective impacts (ecosystem services). The literature review is divided in four parts based on different land use (urban and industrial, agriculture, forest, and nature) and is conducted in accordance with the PRISMA protocol (Page et al., 2021). More than 40000 references have been scanned to filter out 451 relevant studies and to compile a list of drivers for soil and land use changes in the EU. The identified drivers across all land uses have been adjusted and standardised in in-person and online workshops. The set list of drivers is being used to filter the metadata and the presently filtered set of data is sorted according to the EU soil mission's soil health objectives (i.e as represented in the developing and naming of the Think Tanks in WP2), land use, and location. Apart from the use in the think-tanks of the SOLO project (WP2) for R&I roadmap development, the output of this result also corroborates with the WP4 by helping with validating the soil week topics across the partners as well as supporting the prioritization and validation of the regional nodes activities. The output of WP3 is directly of great benefit for stakeholders, policymakers, researchers, and scientists working towards ensuring the future of healthy soils in Europe or in general. Therefore, other forms of publications, opinion, conference or peer reviewed papers, are also written and distributed to communicate the WP3 results.

2 Methodology

Driving force analysis was built upon a comprehensive analytical framework which recognized drivers, pressures, state, impact, and response measures (DPSIR) as fundamental components of soil health (detailed in Section 2.1). The research work was subdivided across four land use types: agriculture, forestry, natural areas, and urban and industrial areas (Figure 1, top). The task leaders and associated partners responsible for carrying out the task were grouped within the four land uses (Figure 1, bottom). The work of the different task groups was lead and coordinated by the WP3 leader, ZALF. To achieve the aim of the deliverable which is to create a typology of the drivers for future changes in soil and land use management, the following three steps were taken:

- Step 1 – Initial inventory and characterisation of drivers for different land uses with the meta-analysis
- Step 2 – Standardisation of the drivers across different land uses
- Step 3 – Identification and differentiation of the regional and general specificity of the drivers.

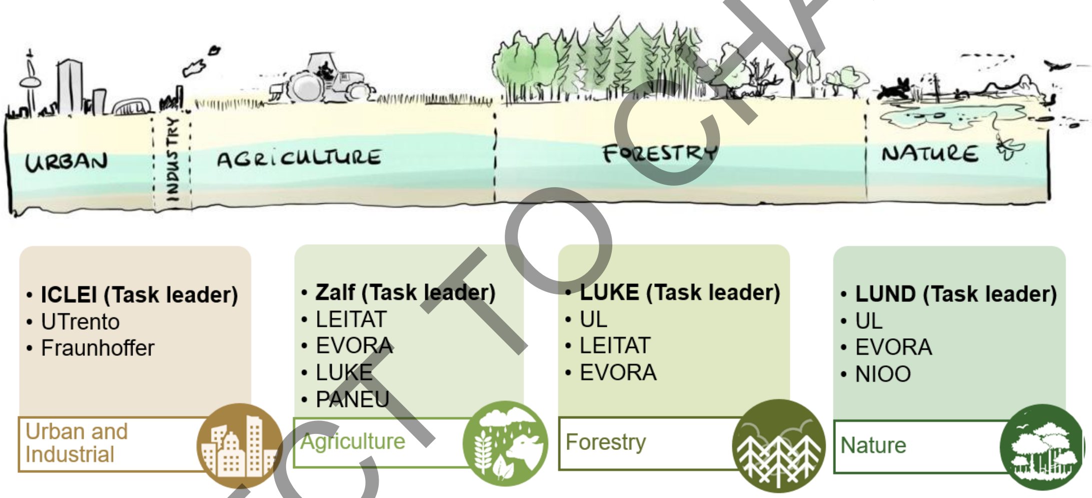

Figure 1 : Top. – Conceptualization of the land use types (Drawings: Joost Fluitsma, sourced from SMS ontology report (https://www.soilmissionsupport.eu/news-2022/ontology), Bottom – Land use sub-types, adjusted with PREPSOIL land use categorisation.

Section 2.2 elaborates the protocol adopted to carry out the steps. The protocol was developed and outlined in detail as a milestoneM1 which was communicated among SOLO partners in June, 2023. The milestone document is available as appendix I.

2.1 Analytical framework - DPSIR

The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework (Figure 2) is a widely-used analytical tool for understanding the complex relationships between human activities and the environment (EEA, 1999; Helming et al., 2018; Schjønning et al., 2015). The DPSIR framework can help to identify and analyse the different factors at various scales that influence soil health. The DIPSR framework has already been adopted in ongoing national and EU projects (BonaRes, SMS, and PREPSOIL). For SOLO WP3, the DPSIR framework is adapted to reflect the research aim, identifying the drivers impacting future soil health across EU and it is represented graphically in the Figure 2. In that regards, S- State of DPSIR is the state of the soil health, i.e. the soil health objectives. The soil health objectives here are represented by the Think Tanks developed in SOLO to reflect on the soil mission objectives. As well as the 8 soil mission objectives (soil erosion, land degradation, soil structure, soil sealing, soil organic carbon, soil literacy, soil pollution, and EU global footprint on soil) and with the addition of soil biodiversity. The I – Impacts in this case are the effect on soil and land based ecosystem services. The P-pressures are the changes that are or will take place in terms of soil and land use, management. The R - Responses are to be designed based on the inputs to ensure soil health and can designed to target the pressures or the state. But the effective response design is done by addressing the root of the issue which in this case are the D - Drivers that caused the changes to take place.

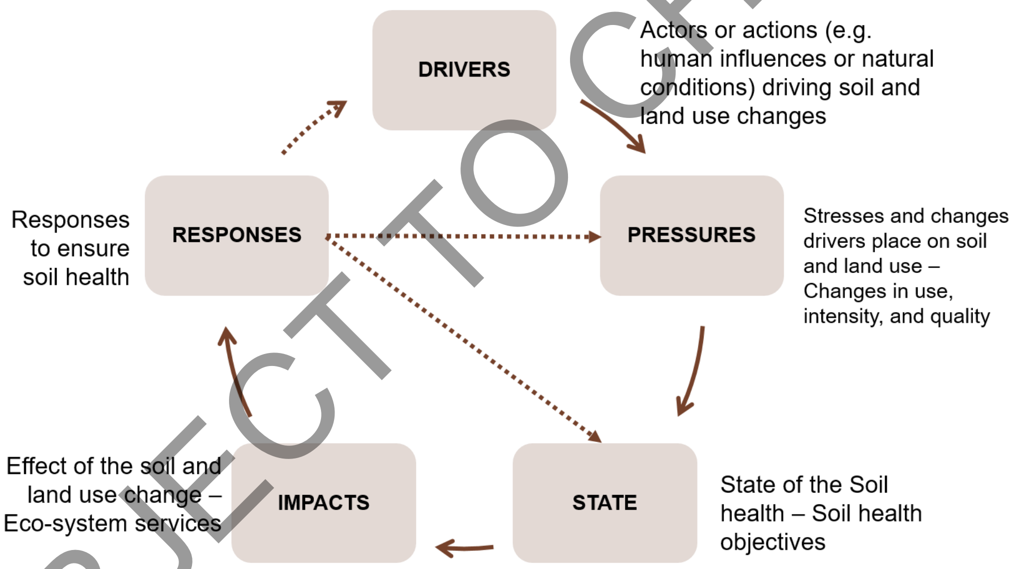

Figure 2 : DPSIR Framework schematic for future soil and land use management for soil health (adapted from EEA (1999))

The drivers that induce changes in soil and land use management and by thus, affecting soil health are multi-faceted, including economic, social, institutional, and environmental factors. Socio-cultural factors such as changes in dietary preference can impact the market demand for crops, and thus, can have a significant impact on land use decisions and soil health. Changes in demography such as population growth, aging of population or rural-urban migration can also influence the use and management of soil and land. For example, aging of rural population can be reflected by the lack of use of the arable land leading to abandonment which can lead to land degradation in some cases and in other, improved soil structure or SOC. Similarly, urbanization can lead to the conversion of agricultural land to sealed land, resulting in soil loss and degradation. Institutional factors such as policies, regulations, and land tenure arrangements can also play a significant role in determining the state of soil health. For example, subsidies for certain crops can incentivize farmers to adopt practices that may negatively impact soil health. Conversely, regulations that require the adoption of sustainable land management practices can promote soil health. Environmental factors such as climate change can also affect soil health greatly. Climate change can lead to changes in precipitation patterns and temperatures, which can affect soil moisture, nutrient availability and erosion vulnerability. Land use change can lead to the conversion of natural ecosystems to agricultural land, resulting in soil degradation and loss of biodiversity.

2.2 Protocol for developing the typology of drivers

A protocol (M1) for meta-analysis was established to carry out the steps identified in methodology to achieve the aim of the deliverable, to develop a typology of drivers of soil health. The drivers were selected according to their potential to motivate the following future changes:

- Changes in use – drivers of anticipated changes in land use compared to the present such as differences in type of use (uniformation, diversification, or gentrification), degree of use (intensification, extensification, or degradation), etc.
- Changes in management – drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc.
- Changes in management quality (smartness) - how well it may integrate multifunctionality and environmental, social and economic services, etc.

2.2.1 Data collection

Step 1 aimed to create the inventory of drivers of changes for different land uses by analysing the existing literature on the topic. PRISMA protocol (Page et al., 2021) was used as a guide and synchronise the meta-analysis process (see appendix 1). The data collection took place in parallel for four land uses so certain standards regarding the timeline, the search engine, language and location have been set (Table 1) prior to the review process. The review was largely limited to the peer reviewed published literature available on Scopus but there were scopes outlined (see appendix 1) to enrich the search with grey literatures.

Table 1: Details of data collection for the meta-analysis

PUBLICATION TYPE:	**PEER-REVIEW, GREY LITERATURE (POLICY REPORTS, EU PUBLICATIONS, ETC)**
TIME LINE	2010-2023 and predictions up to 2100
SEARCH ENGINES	Scopus
KEY WORDS	Select general and specific keywords related to land use types and drivers
LANGUAGE	English and local language (regional specific)
SPATIAL	Regional to European level

An initial set of drivers was set to help start the review process (Table 2 provides an initial set of drivers for all categorised land uses, which is to be updated with new drivers). The drivers are categorised in six sub-categories: technology and management, nature and environment, demography, policy and institutional arrangements, socio-cultural contexts, and economy.

Table 2 : Initial list of drivers to support the meta-analysis

Land Use Type / Drivers Categories	Agriculture	Forest	Urban and Industrial	Natural
Technology and Management	• Digitalisation • Budget • Value chains • Changing farmers attitude • New and abandoned technology practices • Machinery • Agronomic and technological innovations • Novel negative emission solutions • Circular economies • New technologies for recycling and re-use	• Managed forest (Logging) • Non-Managed forest (nature conservation) • Circular production • Value chains • Forest fires • Deforestation • Invasive species • Tree species selection • Pollution	• Urban Sprawl • Novel approaches to fore integrating nature into urban environments through nature based solutions • Restoration • Pesticide free town initiatives	• Abandonment and rewilding • Drought • Land Use change
Nature and Environment	▪ Soil biodiversity ▪ Climate change ▪ Resource depletion ▪ Long-term contamination of soils ▪ Water scarcity and quality	• Climate change • Nitrogen deposition • Pathogens	• Climate change • Urban heat island effect • Flooding • Earth quakes	• Climate change
Policy and Institutional Arrangement	▪ CAP ▪ Price trends ▪ The new Soil health law ▪ Land use policies at regional, national and EU level ▪ Climate policies	International regulations and certifications	• Legal and regulatory constraints • Perverse incentives-adverse economic dynamics	• Regulation of protected areas • Policy – Biodiversity strategy • Sustainable pesticide use directive
Demography	• Population Size • Population age • Rural-Urban Linkages			
Socio-cultural contexts	▪ Dietary preferences ▪ Consumer demands for pesticide free agriculture, ▪ Educational levels Literacy			
Economy	▪ Land ownership ▪ Relative prices of commodities ▪ Energy prices ▪ Market concentration	• Economy • Trade		

2.2.2 Data sorting

The structure for data sorting to take place after the data collection is presented in Table 3 and Table 4. Table 3 provides the format of the first level of the data sorting, in which the following information were filtered out from an individual study: title of the driver(s) and categorisation, source, and brief explanation of the certain characteristics of the identified driver(s). The sorting across the four land uses is co-ordinated online, with both of these tables were compiled in an online excel sheet.

Table 3 : Format for updated list of drivers for future with explanations (example is provided and highlighted)

LIST OF DRIVERS FOR ´INSERT LAND USE TYPE´		SOURCE	EXPLANATION
CATEGORIES	Individual drivers		
TECHNOLOGY AND MANAGEMENT	Digitalisation (for land use agriculture)	EC (2021)	Emerging digital technologies would lead to smart exploitation of ecological processes as well as smart management and monitoring of associated ecosystem services.
NATURE AND ENVIRONMENT	Rows added or deleted if needed		
POLICY AND INSTITUTIONAL ARRANGEMENT	Rows added or deleted if needed		
DEMOGRAPHY	Rows added or deleted if needed		
SOCIO-CULTURAL CONTEXTS	Rows added or deleted if needed		
ECONOMY	Rows added or deleted if needed		

Table 4 provides the format for more detailed information regarding the identified drivers. The first column of the table is for the drivers and the next three columns are grouped under the likelihood to affect different changes in soil, land use, and management quality. The next four columns are grouped under the ubiquity or specific setting (context) in which it is likely to be relevant (more information about the columns are provided in the footnotes). The first column among the four context categories contains the information of location which is usually limited to NUTS0 level within EU33 but if not possible, other location based information such as regional or climatic zone are also included. The next column contains land cover per environmental zone which follows the Corrine land cover classification for the four types of land uses. The third column contains the relevant soil health objective (s) that the driver(s) is associated with. The fourth column in this group is for listing the stakeholders associated, and this is the only column where a set list is not provided. The next group of columns lists the temporal dynamics of the drivers, short term or long term. And the final group of columns states the robustness of the knowledge, if the driver is well studied or the relation is mostly speculation.

Table 4 : Format for updated list of drivers for future with brief exploration

List of drivers for 'Insert land use'		Likely to affect			Ubiquity or specific setting in which it is likely to be relevant				Likely temporal dynamic (frequency)		Robustness of knowledge	
Categories	Individual drivers	Land use change	Land use intensity	Management quality	Location[1]	Land cover per Environmental zone[2]	Relevant soil health objectives[3]	Relevant stakeholders[4]	Short term	Long term	Well established	Uncertain
Technology and Management	Driver 1											
	Driver 2											
	Driver n											

[1] Choose ideally but not limited to the thirty seven options, multiple options (1-33) can be combined together: 1 – 33 EU member states, 34: EU, 35: Europe, 36: Relevant everywhere, 37: Not sure. Other options such as regional climatic zones such as Mediterranean, or drylands are also accepted.

[2] Choose from the following options, multiple options can be combined together (Corine landcover Level 3 identification number in parenthesis, see appendix 8.3). For Urban and Industrial: 1. Continuous urban fabric (111), 2. Discontinuous urban fabric (112), 3. Industrial or commercial units (121), 4. Road and rail network and associated land (122), 5. Port areas (123), 6. Airports (124), 7. Mineral extraction sites (131), 8. Dump sites (132), 9. Construction sites (133), 10. Green urban areas (141), 11. Sport and leisure facilities (142), 12. Relevant everywhere.

For Agriculture: 1. Non-irrigated arable land (211), 2. Permanently irrigated land (212), 3. Rice fields (213), 4. Vineyards (221), 5. Fruit trees and berry plantations (222), 7. Olive groves (223), 8. Pastures (231), 9. Annual crops associated with permanent crops (241), 10. Complex cultivation patterns (242), 11. Land principally occupied by agriculture, with significant areas of natural vegetation (243), 12. Agro-forestry areas (244), 13. Relevant everywhere. 14. Not sure.

For Forestry: 1. Broad-leaved forest (311), 2. Coniferous forest (312), 3. Mixed forest (313), 4. Relevant everywhere. 5. Not sure.

For Nature: 1. Natural grasslands (321), 2. Moors and heathland (322), 3. Sclerophyllous vegetation (323), 4. Transitional woodland-shrub (324), 5. Beaches, dunes, sands (331), 6. Bare rocks (332), 7. Sparsely vegetated areas (333), 8. Burnt areas (334), 9. Glaciers and perpetual snow (335), 10. Inland marshes (411), 11. Peat bogs (412), 12. Salt marshes (421), 13. Salines (422), 14. Intertidal flats (423), 15. Relevant everywhere. 16. Not sure.

Classification based on Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2019). *Updated CLC illustrated nomenclature guidelines*.

[3] Choose from the following ten options, multiple options can be combined together: 1. Land degradation, 2. Soil organic carbon stock, 3. Soil sealing, 4. Soil pollution 5. Soil erosion, 6. Soil structure 7. Soil literacy, 8. EU global footprint on soil, 9. All of them, 10. Not sure. Classification based on SOLO think tank objectives and EEA. (2022b). *Soil monitoring in Europe — Indicators and thresholds for soil health assessments* (EEA report, Issue. , Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J. I., Paracchini, M. L., Abdul Malak, D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A. M., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A. I., . . . Santos-Martín, F. (2020). *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment* (EUR 30161 EN). (JRC Science for policy report, Issue. P. O. o. t. E. Union.

[4] State the relevant stakeholders associated with the driver. There´s no set list provided for this so the task leaders are asked to be as elaborate with their selection as possible. The idea is to collect the relevant stakeholders from all land uses and try to for a categorisation together.

2.2.3 Data standardisation

As the data was collected and sorted by four task groups, it was predicted that there would be needs to align the process from time to time, and most importantly, standardise the drivers in terms of scope and language across all land uses. To facilitate this process, workshops were planned and designed. The timeline for the workshops to take place was set from Dec 2023 - Jan 2024.

2.2.4 Data communication

The communication of the data was designed to take place periodically across the SOLO partners and the wider audience. Initial set of the drivers, grouped across soil health objectives, were to be communicated with the WP2 think tanks to collect their input. The later communications were designed to support all work packages of SOLO. General communication with the wider audience was also planned in form of scientific journal publications and conference proceedings as well as public reports and peer reviewed publications.

2.3 Summary of the meta-analysis – Activities and general outlook

The meta-analysis protocol, as well as the relative work protocol of the WP3, was finalized as Milestone 1 during the period of 01.06 - 19.06.2023. The following sections elaborates on the collection, sorting, standardization and communication of the metadata according to the protocol.

2.3.1 Data collection and sorting

The data curation, as per the PRISMA protocol had taken place for the four land uses during the period between 15.06.2023 to 01.01.2024. Figure 3 – 6 summarises the PRISMA protocol carried out for the four land uses. In general, search strings were developed which were then used to find the initial set of literatures from the data base, Scopus. With the initial filtration criteria, which were the time line and language, and with the exclusion of duplicates, a large part of the literature were already filtered out. Thereafter, the four working groups differentiated by the four land uses proceeded in slightly different ways. Most of the groups applied a next step of filtering the literature relevance based on reviewing the title and abstract. The differentiation of the work was depended on collaboration process between different partners within a task. For nature and agriculture, offline excel table were used to keep track of the literature analysed which was then used to update the online excel table. Urban and forest worked directly on the excel table online. The filtration at that stage focused on more specific criteria such a location of case studies, if it is related to soil health or changes, or just a test of hypothesis (see Figure 3-6 for details). The final selection of studies were analysed for their full text to fill up the sorting tables (4 and 5) in excel. In total, 53,203 literatures has been filtered among four land uses to end up with the final list of 447 studies. An Endnote library was created after the sorting to provide a uniform list of drivers that was used for the following stages as well as to facilitate the development of the deliverable.. Data sorting on the online Excel file and compilation of the offline Endnote library took place during the period of 01.07.2023 to 01.03.2024.

2.3.2 Data standardization and communication

With the data being collected and compiled by four land uses (i.e task groups) separately, it was deemed necessary to standardize the language of the drivers identified (Table 3) as only references (Table 2) were provided rather than a concrete list drivers of future soil or land use or management could be found in the literature. The existing contents up to Oct 2023 of the online Excel file on the list of drivers (Table 3, column 1) of all land uses were grouped and standardized to provide a harmonious list of drivers that would be consistent for the rest of the meta-analysis process. The data standardization took place in two workshops, one in person workshop, November, 2023, and another online workshop in January, 2024. The drivers were first grouped according to their similarity by the WP3 coordinator and during the workshop, the task leaders as well as other members of the SOLO consortium went over them individually to create the standardized set of the drivers. Using this list as a base, the following compilation and sorting of the metadata took place. Consolidation and sorting were done mostly offline with a combination of the following: Word, Endnote and Excel, during 01.11.2023 – 31-04.2024.

Due to the bulk, and complexity of the data, the data is being processed in stages. The following result is the summary of the data being presently processed. It includes the typology of the drivers (section 3.2), which are then sorted according to associated soil health objectives and the location identified (section 3.3). The initial outcomes of this step were communicated to the SOLO consortium in Dec 2023 in Barcelona. And a more final set was shared during the SOLO consortium meeting in Wageningen in April, 2024.

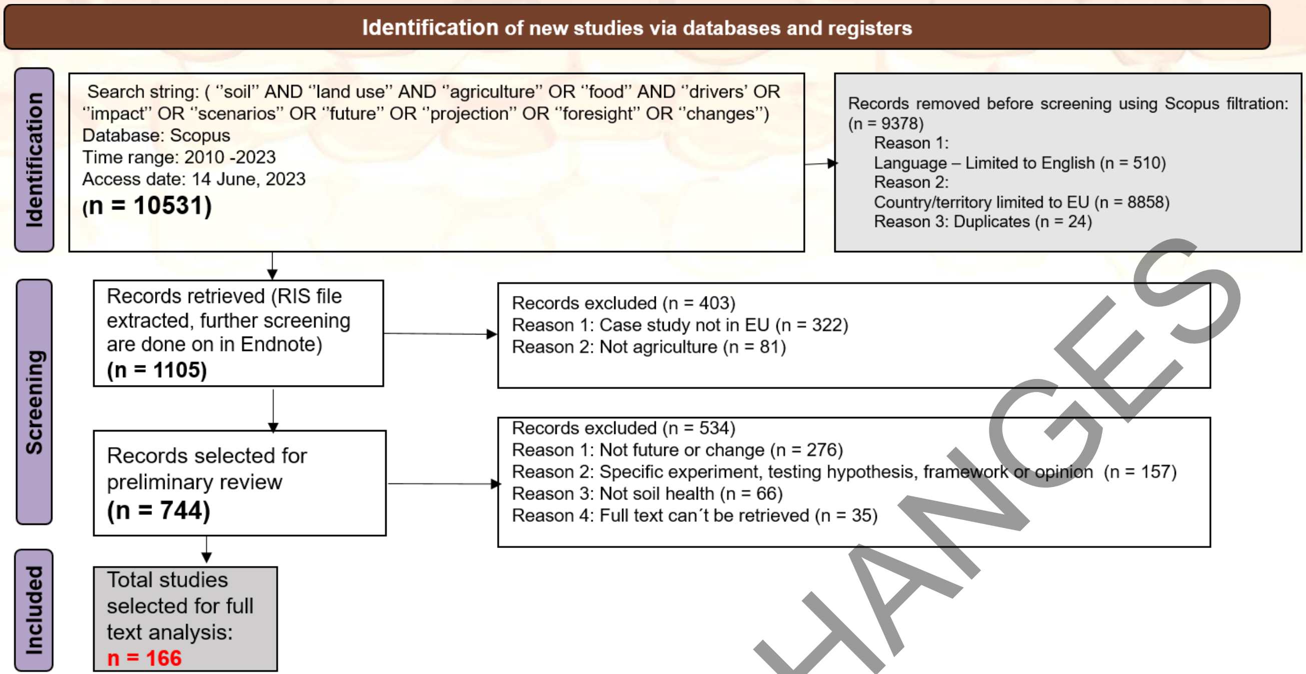

Figure 3: PRISMA flow diagram for literature review for Agriculture land use

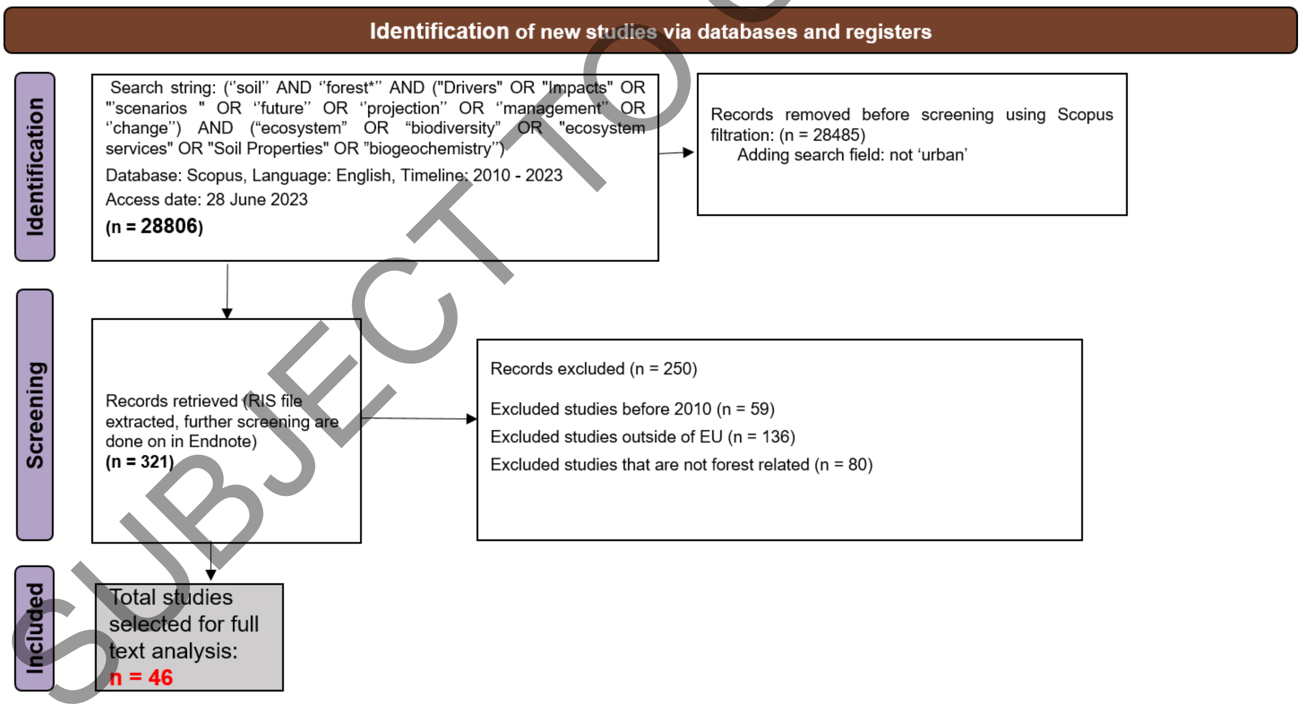

Figure 4: PRISMA flow diagram for literature review for Forest land use

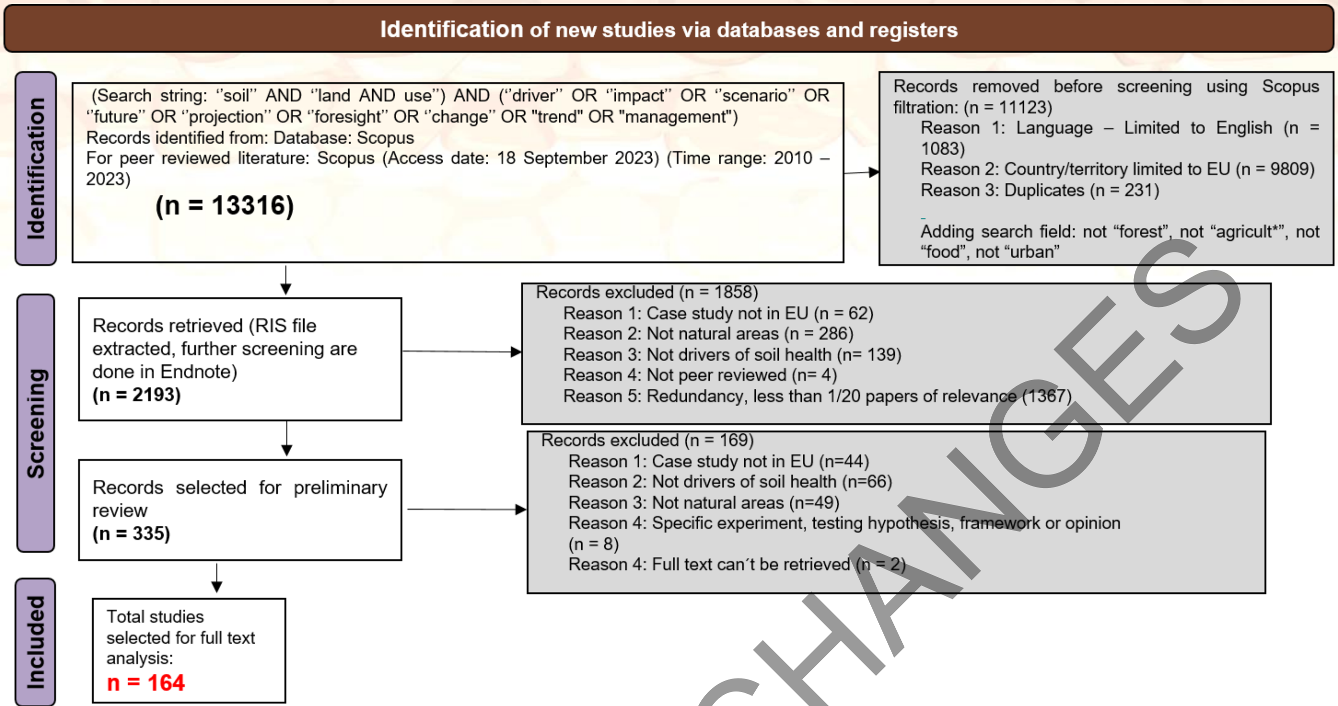

Figure 5: PRISMA flow diagram for literature review for Nature land use

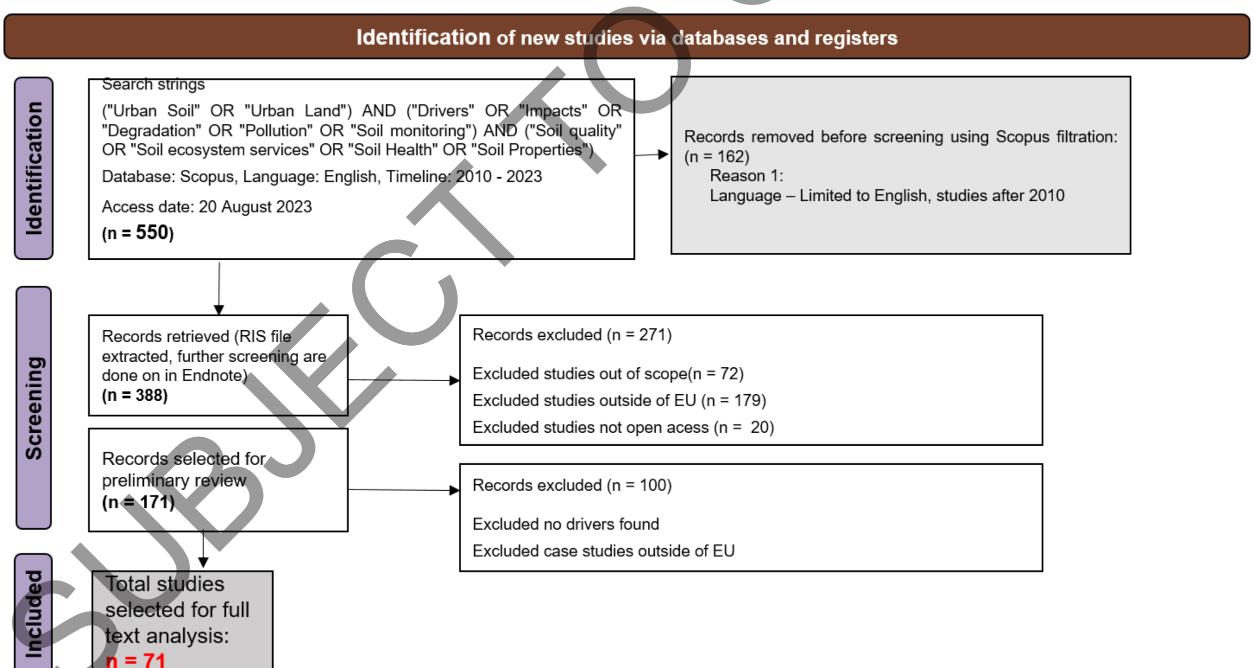

Figure 6: PRISMA flow diagram for literature review for Urban and industrial land use

3 Results

3.1 Typology of drivers

The typology of drivers is a standardised set of all the drivers, identified across all the land uses that could impact the soil and land use change and management. In total, 125 drivers have been listed with 29 drivers in the Technology and management category, 12 drivers in nature and environment category, 12 drivers in the demography category, 43 drivers in the policy and institutional arrangement category, 12 drivers in the socio-cultural context category, and 17 drivers in the economy category. Table 5 presents the list of drivers with the first column consisting of the short code used in the structuring of the following sections, and the second column contains the title of the drivers. Further descriptions are not provided as the titles are considered self-explanatory.

Table 5: Typology of drivers

Short Code	Name of the driver
T	**Category - Technology and Management**
1.	Industrial and commercial activities and subsequent pollution (including traffic)
2.	Emerging novel pollutants (micro or nano plastics)
3.	Frequency and timing of machinery use
4.	Increased size of machinery
5.	Use of fertiliser
6.	Current land management practices
7.	Current soil management practices during construction
8.	Current waste management practices
9.	Current management and regulations about contamination and contaminated sites
10.	Increasing demand for water
11.	Advancement in monitoring and management of water resources
12.	Advancement in tools and models for soil monitoring and land management
13.	Advancement of waste management practices
14.	Advancement in monitoring and management of contaminated sites
15.	Advancement in remote and proximal sensing and imaging
16.	Advancement in artificial surfaces
17.	Recognition of the need and progress towards standardisation of soil health indicators
18.	Recognition of the need for efficient spatial planning strategies across all land uses
19.	Adoption of digital platforms for soil health monitoring and information sharing
20.	Adoption of Nature-based solutions for climate change mitigation (Sustainable practices)
21.	Promotion and acceptance of the use of organic fertiliser, treated sludge and wastewater
22.	Promotion and integration of improved soil sealing and stabilising strategies
23.	Promotion and integration of resilience building through spatial planning

24.	Research and implementation of soil remediation techniques on contaminated sites
25.	Promotion and integration of ecosystem services in spatial planning
26.	Promotion and integration of green infrastructure in urban and industrial areas
27.	Recognition of monetary benefits of ecosystem services in spatial planning
28.	Advancement and adoption of precision agriculture technologies
29.	Advancement and adoption of efficient fertiliser replacement and recovery technologies
N	**Nature and environments**
1.	Climate change
2.	Climate change – Increased temperature
3.	Climate change – Increased precipitation
4.	Climate change – Decreased precipitation
5.	Climate change - Shift in precipitation, temperature, and wind patterns
6.	Extreme weather (including drought, flood, acid rain, wildfires)
7.	Climate change - Prolongation of the growing season due to a warming climate
8.	Climate change - Improved predictive understanding
9.	Climate change – sea level rise
10.	Climate change – need and adoption of strategies for climate change adaptation
11.	Abiotic factors (pH, carbon content, water level)
12.	Invasive species
D	**Demography**
1.	Declining rural population
2.	Decreasing population density in rural areas
3.	Aging of land owners or managers
4.	Migration
5.	Internal migration
6.	Decline in active labour in agriculture
7.	Change in ownership and tenure ship
8.	Limited knowledge transfer between the old and the new generation
9.	Increasing population
10.	Increasing population in urban areas
11.	Population increase and subsequent increase of global demand
12.	Households size and per-capita land consumption
P	**Policy and institutional arrangements**
1.	Global - International strategies, agreements and conventions
2.	Global - International strategies, agreements and conventions -United Nations Environmental Program, Society of Environmental Toxicology and Chemistry (SETAC)

3.	Global - International strategies, agreements and conventions - SDG
4.	Global - International strategies, agreements and conventions - United Nations Convention to Combat Desertification (UNCCD)'s Land Degradation Neutrality Programme (UNCCD, 2015)
5.	Global - International strategies, agreements and conventions - COP26 Glasgow Climate Pact
6.	EU-EU level strategies, agreements and conventions
7.	EU-EU level strategies, agreements and conventions - European green deal (including circular economy action plan)
8.	EU-EU level strategies, agreements and conventions - Zero pollution action plan
9.	EU-EU level strategies, agreements and conventions - EU soil strategy
10.	EU-EU level strategies, agreements and convention - Biodiversity strategy for 2030
11.	EU - EU level strategies, agreements and conventions- Strategic Approach to Pharmaceuticals in the Environment COM/2019/128 final
12.	EU-EU level directives and legislations - European Climate Law 2021/1119
13.	EU-EU level directives and legislations – Habitats directive 92/43/EEC
14.	EU-EU level directives and legislations – Birds directive 2009/147/EC
15.	EU-EU level directives and legislations - Sewage sludge directive
16.	EU-EU level directives and legislations – Urban wastewater directive
17.	EU-EU level directives and legislations - Industrial Emissions Directive
18.	EU-EU level directives and legislations - Nature Restoration Law 2022/0195
19.	EU-EU level directives and legislations - Proposed EU soil monitoring law 2023/0232
20.	EU - EU level directives and legislations - Common Agricultural Policy (CAP)
21.	EU - EU level directives and legislations - Common Agricultural Policy (CAP) - Pillar 1 support payments and trade liberalisation
22.	EU - EU level directives and legislations - Common Agricultural Policy (CAP) - Pillar 2 Natura 2000
23.	EU-EU level directives and legislations - Renewable Energy Directive (EU) 2023/2413
24.	EU - EU level directives and legislations - Nitrates Directive 91/676/EEC
25.	EU - EU level directives and legislations – Water Framework Directive
26.	EU - EU level directives and legislations – Water Framework Directive - Common Market Organisation regulation for wine production (CE 555/2008)
27.	EU - EU level directives and legislations – Reform of the Landfill directive
28.	EU - Horizon Europe soil mission - funding for research
29.	National-National level strategies, agreements and conventions
30.	National-National level strategies, agreements and conventions - Soil Support Programme and LKV (Decree for the retention of life basics and cultural landscape) Switzerland
31.	National - National level strategies, agreements and conventions – Spanish Forest Plan
32.	National - National level legislations and laws

33.	National - National level legislations and laws –Stratégie Nationale Bas-Carbone 2020 (France)
34.	National - National legislations and laws - Renewable Energy Act (German: EEG)
35.	National - National legislations and laws - German fertilizer ordinance
36.	Combined effect of Global, EU, National measures
37.	Combined effect of International, EU, National measures to limit and control soil pollution
38.	EU - Combined effect of EU policies (EU climate adaptation strategy COM(2021) 82 final, Biodiversity strategy for 2030, Regional policy for EU (Cohesion policy))
39.	EU-Combination of strategies, policies and legislation related to Agriculture and Environment (European Green deal, Farm to fork strategy, Farm to for, Biodiversity strategy for 2030, European Climate law 2021/1119, CAP)
40.	EU-Combination of strategies, policies and legislation related to Urban greening (Biodiversity strategy for 2030, Nature Restoration Law 2022/0195)
41.	Combination of strategies, policies and legislation related to energy (European Climate law 2021/1119, Renewable Energy Directive (EU) 2023/2413, national policies)
42.	Research demands by EC
43.	Conflicts between regional and local policies
S	**Socio-cultural context**
1.	Participatory decision making for land use planning and management
2.	Cultural values and practices related to land and soil
3.	Increasing societal demands for food security
4.	Changes in consumption pattern and demand
5.	Changes in consumer/user demand
6.	Land managers´ attitude and willingness
7.	Miscommunication between science and practice
8.	Increasing awareness and literacy of soil based ecosystem services
9.	Increased interest in urban agriculture
10.	Growing concerns about soil health in industrial and urban areas
11.	lack of knowledge transfer between scientists and stakeholders
12.	Need for soil related policies to reflect the need for societal demand
E	**Economy**
1.	Increasing demand for bioenergy
2.	Increasing demand for solar energy
3.	Increasing demand for tourism/recreational use
4.	Emerging carbon markets
5.	Emerging e-commerce market
6.	Urbanisation
7.	Increasing demand for food
8.	Expansion of rural settlements

9.	Non-favourable economic condition in rural areas
10.	Armed conflicts
11.	Increasing market price
12.	Decreasing market price
13.	Market pressure to ensure profitability and heterogeneity
14.	Market volatility
15.	Improved access to global market
16.	Increasing demand for industrial areas
17.	Historical mining

3.2 Drivers for Soil health objectives

The analysed data has been sorted according to the needs and suggestions by the Think tank (WP2) leaders expressed during the SOLO consortium meeting in Wageningen, to support the work for roadmap development. The aim was also to structure the data to be easily appropriated by the other work packages, to be used for validation and comparison for the regional nodes activities and soil. The data is sorted in tables 7 - 16 consisting of the short code for the drivers (see table 6) and the associated land use, location, and source.

3.2.1 Relevant to all soil health objectives

Table 6 presents the studies that have not made differences in soil health objectives or refereed to soil health in general. These drivers, as well as their location and associated land uses, are to be taken into consideration to all soil health objectives. .

Table 6: List of drivers relevant to all soil health objectives

Short code	Land use	Location	Citation
D 1	Urban	Relevant everywhere	(EC, 2023a)
D 10	Urban	Relevant everywhere	(Berhe, 2019)
D 3	Forest	Finland	(Häyrinen et al., 2014)
D 9	Forest	Relevant everywhere	(Hatten & Liles, 2019; Montanarella et al., 2016)
E 14	Forest	Finland	(Häyrinen et al., 2014)
		Relevant everywhere	(Montanarella et al., 2016)
E 6	Agriculture	Spain	(Barbero-Sierra et al., 2013)
		Greece	(Salvati et al., 2014)
	Forest	Finland	(Häyrinen et al., 2014)
	Urban	EU	(EC, 2023a)
E 7	Agriculture	Relevant everywhere	(Evans et al., 2020)
	Nature	Germany	(Stempfhuber et al., 2014)
N 1	Forest	Relevant everywhere	(Hatten & Liles, 2019)
	Urban	Relevant everywhere	(Brevik, 2013)
N 2	Forest	Relevant everywhere	(Hatten & Liles, 2019)
N 5	Urban	Germany	(Kahlenborn et al., 2021)
N 6	Forest	Relevant everywhere	(Hatten & Liles, 2019)
	Urban	Germany	(Kahlenborn et al., 2021)
N 11	Nature	Germany	(Stempfhuber et al., 2014)
P 1	Urban	Relevant everywhere	(Lal et al., 2012)
P 7	Urban	Relevant everywhere	("COM(2019) 640 final," 2019)
P 9	Agriculture	EU	(Banwart et al., 2011)
	Urban	EU	("COM(2021) 699 final," 2021)
P 18	Urban	EU	("COM(2022) 304 final," 2022)

P 19	Urban	EU	("COM(2023) 416 final," 2023)
P 28	Urban	EU	(EC, 2023b)
P 42	Urban	EU	(Veerman et al., 2020)
S 10	Urban	Mediterranean	(Seifollahi-Aghmiuni et al., 2022)
S 3	Agriculture	EU (north)	(Zwetsloot et al., 2021)
S 4	Forest	Relevant everywhere	(Hatten & Liles, 2019)
S 5	Nature	Spain	(Schnabel et al., 2013)
S 6	Forest	Finland	(Häyrinen et al., 2014)
S 8	Agriculture	Italy	(Cabini et al., 2018)
	Forest	Finland	(Häyrinen et al., 2014)
	Urban	Germany	(Lehmler et al., 2023)
T 1	Forest	Relevant everywhere	(Hatten & Liles, 2019; Lilleskov et al., 2019)
T 12	Agriculture	Relevant everywhere	(Bilas et al., 2022; Mueller et al., 2010)
	Forest	Mediterranean	(Moindjié et al., 2022)
	Urban	Relevant everywhere	(Bouzouidja et al., 2021)
T 15	Urban	Europe	(Erős et al., 2023)
T 17	Agriculture	Relevant everywhere	(Banwart et al., 2011)
	Forest	Relevant everywhere	(Gatica-Saavedra et al., 2022; Hatten & Liles, 2019)
	Urban	Relevant everywhere	(Cardoso et al., 2013)
T 20	Nature	Spain	(Schnabel et al., 2013)
T 23	Urban	Germany	(Dietze & Feindt, 2023)
T 25	Agriculture	Switzerland	(Jaligot & Chenal, 2019)
T 26	Forest	Relevant everywhere	(Hatten & Liles, 2019)
		Spain	(Gatica-Saavedra et al., 2022)
		Greece	(Tomao et al., 2017)
	Urban	Poland	(Burszta-Adamiak et al., 2023)
		Germany	(Lehmler et al., 2023)
		Austria	(Minixhofer et al., 2022)
T 27	Urban	Poland	(Sikorski et al., 2021)
T 3	Forest	Relevant everywhere	(Hatten & Liles, 2019)
T 5	Forest	Relevant everywhere	(Lilleskov et al., 2019)
T 6	Forest	Relevant everywhere	(Hatten & Liles, 2019; Lilleskov et al., 2019)

3.2.2 Land degradation

Land degradation in the EU soil mission objectives is associated with desertification, and it is appropriated for this literature review according to the definition provided by UNDDD as 'Degraded land in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic fluctuations and human activities' (UNDDD, 2010). UNDDD (2010) also defined degraded land as 'the result of human-induced actions which exploit land, causing its utility, biodiversity, soil fertility, and overall health to decline'. In the texts from the literature, several other concepts were also included when considering land degradation such as salinization, forest fires, aridity, drought, etc. As elaborated from the definitions, land degradation is a vast topic that often coincides with one or more other soil health objectives. It is often used as an umbrella term encompassing many degradation processes taking place on soil and land. The vastness of the topic is reflected in the literature as many drivers across all the land uses have been identified for land degradation. SMS ontology report (Nougues & Brils, 2023) is used for the definitions cited as well as clarifications of the concepts associated. Table 7 summarises the information from the literature that have specifically, but not limited to, referred to land degradation as per definitions and the associated drivers. The associated drivers in Table 7 are referred to in short code followed by the location and the source reference.

Table 7: List of drivers relevant for land degradation

Short code	Land use	Location	Citation
D 1	Agriculture	Spain	(Bruno et al., 2021)
	Nature	Spain	(Vázquez et al., 2020)
D 2	Agriculture	Relevant everywhere	(Falcucci et al., 2007)
D 3	Agriculture	Spain	(Viedma et al., 2015)
D 9	Agriculture	Mediterranean	(Ben Hamed et al., 2021; Scordia et al., 2020)
		Spain	(Jeong, 2018)
		Relevant everywhere	(Lal, 2010; Pereira et al., 2020; Schultz & Stoll, 2010)
	Nature	Italy	(Egidi et al., 2021; Salvati et al., 2016)
E 1	Agriculture	Relevant everywhere	(Andrea et al., 2018; Haughey et al., 2023; Lal, 2010)
		Mediterranean	(Scordia et al., 2020)
		Spain	(Vargas-Amelin & Pindado, 2014)
E 2	Nature	Relevant everywhere	(Carvalho et al., 2023)
E 3	Forest	Finland	(Malmivaara-Lämsä et al., 2008)
E 4	Agriculture	Drylands	(Bisaro et al., 2014)
E 6	Agriculture	Spain	(Navarro Pedreño et al., 2012)
		Germany, Czech republic, Slovakia	(Sušnik et al., 2022)
	Urban	Relevant everywhere	(Oliveira et al., 2018)
E 7	Agriculture	Mediterranean	(Ben Hamed et al., 2021; Scordia et al., 2020)
		Relevant everywhere	(Haughey et al., 2023; Lal, 2010; Schultz & Stoll, 2010)
		Spain	(Vargas-Amelin & Pindado, 2014)
	Nature	Germany	(Boeddinghaus et al., 2019; Herold et al., 2014; Nitsch et al., 2012)
		Italy	(Gianinetto et al., 2019)

E 10	Agriculture	Past and present active war zones	(Pereira et al., 2020)
E 10	Urban	Ukraine	(Kolodezhna, 2023)
E 11	Agriculture	Drylands	(Bisaro et al., 2014)
E 12	Nature	Italy	(Lelli et al., 2023)
E 13	Agriculture	Spain	(Jeong, 2018)
E 14	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
E 15	Agriculture	Italy	(Debolini et al., 2015)
E 16	Urban	Poland	(Starczewski et al., 2023)
N 1	Agriculture	Drylands	(Bisaro et al., 2014)
		Southern Europe	(D'Odorico et al., 2013)
		Germany, Czech republic, Slovakia	(Sušnik et al., 2022)
	Nature	Italy	(Egidi et al., 2021)
		Relevant everywhere	(Sardans & Peñuelas, 2015)
N 2	Agriculture	Relevant everywhere	(Haughey et al., 2023; Kath et al., 2019; Lal, 2010)
		Czech republic	(Hlavinka et al., 2015)
		Portugal	(Tomaz et al., 2020)
	Nature	Europe	(Fagúndez, 2013)
		Poland, Slovakia	(Hájek et al., 2020)
		Italy	(Lelli et al., 2023; Molinari, 2014; Napoleone et al., 2021)
		Relevant everywhere	(Schlingmann et al., 2020)
N 3	Nature	France	(Landré et al., 2020)
N 4	Agriculture	Spain	(Perpiña Castillo et al., 2020)
		Mediterranean	(Ondrasek & Rengel, 2021)
N 5	Agriculture	Mediterranean	(Ben Hamed et al., 2021; Scordia et al., 2020)
		Spain	(Jeong, 2018)
		Relevant everywhere	(Kammann et al., 2017; Schultz & Stoll, 2010)
		Czech republic	(Hlavinka et al., 2015)
	Nature	Europe	(Almendra-Martín et al., 2022)
		Italy	(Egidi et al., 2021; Gianinetto et al., 2019; Salvati et al., 2016)
		Germany	(Gruss et al., 2022)
		Europe	(Horion et al., 2019; Panagos et al., 2017)
		Greece	(Karamesouti et al., 2023)
		Switzerland	(Midolo et al., 2021)
		Central western Europe	(van der Linden et al., 2019)
		Relevant everywhere	(van der Schalie et al., 2021; Yin et al., 2019)
N 6	Agriculture	Mediterranean	(Ben Hamed et al., 2021; Scordia et al., 2020)
		Relevant everywhere	(Jones, 2016; Lal, 2010)
	Nature	Relevant everywhere	(Gevaert et al., 2018; Santin & Doerr, 2016; Sardans & Peñuelas, 2015)
		Austria	(Ingrisch et al., 2018)
		Ireland	(Kimberley et al., 2012)

		France	(Leitinger et al., 2015)
		Italy	(Molinari, 2014)
		Switzerland	(Stampfli et al., 2018)
N 9	Nature	Netherlands	(Hoogland et al., 2012)
N 11	Nature	Germany	(Herold et al., 2014)
P 2	Nature	Relevant everywhere	(De Laurentiis et al., 2019)
P 3	Agriculture	Relevant everywhere	(Haughey et al., 2023)
	Nature	Europe	(Horion et al., 2019)
		Relevant everywhere	(Schillaci et al., 2023; Stoorvogel et al., 2017)
		Italy	(Smiraglia et al., 2019)
		Germany	(Wunder & Bodle, 2019)
P 4	Nature	Europe	(Horion et al., 2019)
		Relevant everywhere	(Schillaci et al., 2023)
P 7	Agriculture	EU	(Orgiazzi et al., 2022; P. Panagos, A. Muntwyler, et al., 2022)
	Nature	EU	(Schillaci et al., 2023)
P 8	Agriculture	EU	(Orgiazzi et al., 2022)
P 9	Agriculture	EU	(Orgiazzi et al., 2022)
		Spain	(Vargas-Amelin & Pindado, 2014)
		Western Europe	(Virto et al., 2015)
	Nature	Italy	(Gianinetto et al., 2019)
		Relevant everywhere	(Hák et al., 2016)
		Europe	(Pulleman et al., 2012)
P 10	Agriculture	EU	(Orgiazzi et al., 2022)
	Nature	Italy	(Farris et al., 2010)
P 11	Nature	Poland, Slovakia	(Hájek et al., 2020)
P 13	Nature	Estonia	(Leppik et al., 2015)
P 20	Agriculture	Peatland	(Buschmann et al., 2020)
		Netherlands	(Norris et al., 2021)
		Spain	(Vargas-Amelin & Pindado, 2014)
		Western Europe	(Virto et al., 2015)
		Italy	(Debolini et al., 2015)
	Nature	Spain	(Aldezabal et al., 2015)
		Greece	(Karamesouti et al., 2018; Kosmas et al., 2015)
		Germany	(Nitsch et al., 2012)
		Relevant everywhere	(Schillaci et al., 2023)
P 26	Agriculture	Italy	(Debolini et al., 2015)
P 31	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
P 36	Agriculture	Relevant everywhere	(Prager et al., 2011)
P 41	Agriculture	Drylands	(Bisaro et al., 2014)
S 4	Agriculture	Drylands	(Bisaro et al., 2014)
		Relevant everywhere	(Lal, 2010)
		EU	(Saget et al., 2020)
S 5	Agriculture	Beligium	(De Schrijver et al., 2012)

		Relevant everywhere	(Haughey et al., 2023; Pereira et al., 2020)
	Nature	Sweden	(Bahr et al., 2012)
		Italy	(Catorci & Gatti, 2010)
		Portugal	(Costa et al., 2013)
		Poland	(Cybulak et al., 2019)
		Austria	(Ingrisch et al., 2018)
		Greece	(Kastridis & Kamperidou, 2015)
		Estonia	(Leppik et al., 2013, 2015)
		Italy	(Molinari, 2014)
		Spain	(Peco et al., 2012)
		Norway	(Potthoff & Stroth, 2016)
		Spain	(Ries, 2010)
		France	(Robson et al., 2010)
		Spain	(Sáenz de Miera et al., 2020)
		Germany	(Gruss et al., 2022; Schrautzer et al., 2016; Socher et al., 2012)
		Mediterranean	(Souza-Alonso et al., 2017)
		Switzerland	(Stampfli et al., 2018)
		Denmark	(Timmermann et al., 2015)
S 6	Agriculture	Relevant everywhere	(Lal, 2010; Schröder et al., 2020; Turck et al., 2023)
		Netherlands	(Norris et al., 2021)
S 10	Urban	Relevant everywhere	(Carla S. S. Ferreira et al., 2018)
T 5	Nature	Europe	(Fagúndez, 2013)
		Poland, Slovakia	(Hájek et al., 2020)
		Germany	(Heinze et al., 2015)
		Relevant everywhere	(Schlingmann et al., 2020)
T 6	Forest	Finland	(Finer et al., 2021)
	Nature	Germany	(Heinze et al., 2015; Socher et al., 2012)
		Austria, France	(Szukics et al., 2019)
T 10	Agriculture	Relevant everywhere	(Schultz & Stoll, 2010)
		Spain	(Vargas-Amelin & Pindado, 2014)
		Mediterranean	(Ondrasek & Rengel, 2021)
T 11	Agriculture	Relevant everywhere	(Schultz & Stoll, 2010)
		Germany, Czech republic, Slovakia	(Sušnik et al., 2022)
		Spain	(Vargas-Amelin & Pindado, 2014)
T 12	Agriculture	Relevant everywhere	(Weiss et al., 2020)
		Mediterranean	(Ondrasek & Rengel, 2021)
		EU	(Orgiazzi et al., 2022)
		Czech republic	(Hlavinka et al., 2015)
T 14	Urban	EU	(EEA, 2022a)
T 15	Agriculture	EU	(Grillakis et al., 2021)
		Relevant everywhere	(Kath et al., 2019; Schultz & Stoll, 2010; Weiss et al., 2020)
		Spain	(Navarro Pedreño et al., 2012)

		Mediterranean	(Ondrasek & Rengel, 2021)
T 17	Agriculture	Western Europe	(Virto et al., 2015)
		EU	(Orgiazzi et al., 2022)
	Nature	Poland, Slovakia	(Hájek et al., 2020)
T 18	Agriculture	Spain	(Navarro Pedreño et al., 2012)
		Spain	(Vargas-Amelin & Pindado, 2014)
	Nature	Italy	(Assennato et al., 2020)
T 19	Agriculture	EU	(Orgiazzi et al., 2022)
T 20	Agriculture	Mediterranean	(Ben Hamed et al., 2021; Ondrasek & Rengel, 2021; Scordia et al., 2020)
		Relevant everywhere	(Haughey et al., 2023; Schultz & Stoll, 2010)
		EU	(P. Panagos, A. Muntwyler, et al., 2022)
		Germany, Czech republic, Slovakia	(Sušnik et al., 2022)
		Spain	(Vargas-Amelin & Pindado, 2014)
		Czech republic	(Hlavinka et al., 2015)
	Nature	Spain	(Múgica et al., 2018)
		Relevant everywhere	(Santin & Doerr, 2016)
T 23	Agriculture	Spain	(Jeong, 2018)
	Urban	EU	(Egidi et al., 2020)
T 27	Nature	Austria	(Haslmayr et al., 2016)
		Relevant everywhere	(Jónsson & Davíðsdóttir, 2016)
T 28	Agriculture	Relevant everywhere	(Weiss et al., 2020)
		Mediterranean	(Ondrasek & Rengel, 2021)

3.2.3 Soil organic carbon

The Food and Agriculture Association of The United Nations (FAO) defines Soil organic carbon (SOC) as 'Soil organic matter (SOM) is the portion of organic residues in soil in various stages of decay and the main component of SOM is carbon, also known as soil organic carbon (SOC). ' (FAO, 2024) and this definition is appropriated for this literature review. SOC is a widely studied and researched topic with many associated concepts and the SMS ontology report (Nougues & Brils, 2023) presents a good summary of description and source of many of those terminologies. SOC is a vastly explored topic across all land uses and Table 8 summarises the information from the literature that have specifically, but not limited to, referred to SOC as per definitions and the associated drivers. The associated drivers presented in Table 8 are referred to in short code followed by the location and the source references.

Table 8: List of drivers relevant for soil organic carbon

Short code	Land use	Location	Citation
D 1	Nature	Austria, Italy	(Stefanie Meyer et al., 2012)
		Spain	(Vázquez et al., 2020)
D 9	Agriculture	Relevant everywhere	(Lal, 2010)
E 1	Agriculture	Relevant everywhere	(Lal, 2010)
		EU	(Solinas et al., 2021)
E 4	Agriculture	Drylands	(Bisaro et al., 2014)
		EU	(Smith, 2012)
E 6	Agriculture	Spain	(Navarro Pedreño et al., 2012)
		Europe	(Thapa et al., 2021)
	Forest	Spain	(Francos et al., 2019)
E 7	Agriculture	Relevant everywhere	(Lal, 2010)
	Nature	Germany	(Nitsch et al., 2012; Zistl-Schlingmann et al., 2020)
E 8	Agriculture	Austria	(Baumgarten et al., 2021)
E 11	Agriculture	Spain	(Parras-Alcántara et al., 2013)
E 13	Agriculture	Peatland	(Buschmann et al., 2020)
		Spain	(Fernández-Guisuraga et al., 2022; González-Rosado et al., 2023; Parras-Alcántara et al., 2013)
	Nature	Germany	(Seeber et al., 2022)
N 1	Agriculture	Relevant everywhere	(Adil et al., 2022)
		Mediterranean	(Solinas et al., 2021)
	Forest	Relevant everywhere	(Nandal et al., 2023)
	Nature	Austria	(Fuchslueger et al., 2019)
		Relevant everywhere	(Mathieu et al., 2015)
		France	(Meersmans et al., 2012)
		Germany	(Zistl-Schlingmann et al., 2020)
N 2	Agriculture	Relevant everywhere	(Dangal et al., 2022; Lal, 2010)
		Czech republic	(Hlavinka et al., 2015)
	Nature	Spain	(Albaladejo et al., 2013)

		Relevant everywhere	(Batjes, 2014; Yumashev et al., 2022)
		Switzerland	(Gómez Giménez et al., 2019)
		Sweden	(Kleinen & Brovkin, 2018)
		France	(Meersmans et al., 2016)
		Denmark	(Reinsch et al., 2013)
N 4	Nature	France	(Meersmans et al., 2016)
N 5	Agriculture	Finland	(Heikkinen et al., 2022)
		Italy	(Dal Ferro et al., 2018)
		Czech republic	(Hlavinka et al., 2015)
	Nature	Relevant everywhere	(Abdalla et al., 2014; Clark et al., 2010; Gottschalk et al., 2012)
		Spain, Italy, Portugal	(Catania et al., 2022)
		Spain, Portugal	(Matías et al., 2021)
		Europe	(Podmanicky et al., 2011; Yigini & Panagos, 2016)
		Germany	(Seeber et al., 2022)
N 6	Agriculture	Relevant everywhere	(Lal, 2010)
	Nature	Spain	(Albaladejo et al., 2013)
		Sweden	(Brangarí et al., 2022)
		Austria	(Ingrisch et al., 2020)
N 7	Agriculture	Sweden, Finland, Norway, Denmark	(Unc et al., 2021)
N 8	Nature	Europe	(Yigini & Panagos, 2016)
P 3	Agriculture	Relevant everywhere	(Baartman et al., 2022)
	Nature	Relevant everywhere	(Cagnarini et al., 2019)
P 5	Agriculture	Finland	(Ťupek et al., 2021)
	Forest	Relevant everywhere	(Nandal et al., 2023)
P 13	Nature	Norway	(Johansen et al., 2019)
P 20	Agriculture	Italy	(Borrelli et al., 2016)
		Germany	(Früh-Müller et al., 2019)
		EU	(Lugato et al., 2017)
		Netherlands	(Norris et al., 2021)
		Spain	(Fernández-Guisuraga et al., 2022; Parras-Alcántara et al., 2013; Vicente-Vicente et al., 2017)
	Nature	Germany	(Nitsch et al., 2012)
P 35	Nature	Germany	(Zistl-Schlingmann et al., 2020)
P 39	Agriculture	Austria	(Baumgarten et al., 2021)
P 43	Agriculture	Sweden, Finland, Norway, Denmark	(Unc et al., 2021)
S 3	Agriculture	Relevant everywhere	(Lal, 2010)
S 4	Agriculture	Relevant everywhere	(Dumont et al., 2019; Lal, 2010)
		Spain	(González-Rosado et al., 2023)
S 5	Nature	Italy	(D'Acqui et al., 2015)

		Austria	(Harris et al., 2018)
		Norway	(Johansen et al., 2019)
		Spain, Portugal	(Matías et al., 2021)
		France	(Meersmans et al., 2012)
		Austria, Italy	(S Meyer et al., 2012)
		Germany	(Meyer et al., 2022)
		Spain	(Pulido-Fernández et al., 2013)
S 11	Agriculture	Austria	(Baumgarten et al., 2021)
T 1	Nature	Switzerland	(Gómez Giménez et al., 2019)
	Urban	Relevant everywhere	(Allen et al., 2011)
T 2	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 3	Forest	Italy	(Picchio et al., 2012)
		Finland	(Smolander et al., 2019)
		EU (Temparate, Boreal)	(Barberá et al., 2019)
T 5	Forest	EU (Temparate, Boreal)	(Barberá et al., 2019)
	Nature	Germany	(Zistl-Schlingmann et al., 2020)
T 6	Agriculture	France	(Drewer et al., 2016; Dufossé et al., 2014)
	Forest	EU (Temparate, Boreal)	(Barberá et al., 2019)
		Relevant everywhere	(Frac et al., 2018)
	Nature	Relevant everywhere	(Smith, 2014)
T 12	Agriculture	Italy	(Dal Ferro et al., 2018)
		EU	(Lugato et al., 2014; Lugato et al., 2017; Revill et al., 2013)
		Czech republic	(Hlavinka et al., 2015)
	Forest	Relevant everywhere	(Nandal et al., 2023)
T 15	Agriculture	EU	(Lugato et al., 2017; Revill et al., 2013)
		Spain	(Navarro Pedreño et al., 2012)
		Relevant everywhere	(Poeplau & Don, 2015)
	Forest	Relevant everywhere	(Nandal et al., 2023)
	Nature	Peatland	(Lees et al., 2018)
T 17	Agriculture	EU	(Lugato et al., 2017)
	Forest	Relevant everywhere	(Frac et al., 2018)
T 18	Agriculture	Spain	(Navarro Pedreño et al., 2012)
T 20	Agriculture	Relevant everywhere	(Baartman et al., 2022; Shahane & Shivay, 2021)
		Spain	(Antón et al., 2021; Díaz de Otálora et al., 2021; Vicente-Vicente et al., 2017)
		Italy	(Dal Ferro et al., 2018)
		EU	(Lugato et al., 2014; Lugato et al., 2017; Smith, 2012; Solinas et al., 2021)
		Switzerland	(Yang et al., 2021)

		Germany	(Tanneberger et al., 2020)
		Czech republic	(Hlavinka et al., 2015)
	Nature	Relevant everywhere	(Fryer & Williams, 2021)
T 21	Agriculture	Relevant everywhere	(Shahane & Shivay, 2021)
T 24	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018; Malone et al., 2023)
T 25	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 26	Forest	Spain	(Barberá et al., 2019; Francos et al., 2019)
		Relevant everywhere	(Korboulewsky et al., 2016; Nandal et al., 2023)
		Slovakia	(Bobuľská et al., 2019)
T 27	Nature	Portugal	(Sil et al., 2017)

3.2.4 Soil sealing

Sealed soil are defined by SMS ontology report (Nougues & Brils, 2023) who appropriated the definition from Prokop et al (Prokop & Jobstmann, 2011) as 'Sealed soils can be defined as the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.)'. The SMS ontology report (Nougues & Brils, 2023) is used to source the definition for soil sealing and should be used to for the description of the associated terminologies. Soil structure is a relatively less explored topic in the literature and commonly it is limited to urban settings, but it was also largely mentioned in literatures specific to agriculture land use. Table 9 summarises the information from the literature that have specifically, but not limited to, referred to soil pollution as per definitions and the associated drivers. The associated drivers in Table 9 referred to in short code followed by the location and the source references.

Table 9: List of drivers relevant for soil sealing

Short code	Land use	Location	Citation
D 12	Urban	Europe	(Haase et al., 2013)
E 5	Urban	Italy	(Munafò, 2022)
E 6	Urban	Eastern Europe	(Addai et al., 2022)
		Relevant everywhere	(Dadashpoor & Ahani, 2021; Paul & Rakshit, 2022)
		EU	(EEA, 2023; Jóźwik et al., 2022)
		France	(Libessart et al., 2022)
	Agriculture	Germany, Spain, Italy, Netherlands, Albania	(Aksoy et al., 2017)
		Relevant everywhere	(Pereira et al., 2020)
		Spain	(Navarro Pedreño et al., 2012)
		Slovenia	(Robinson et al., 2012)
E 8	Agriculture	Austria	(Aust et al., 2020)
S 1	Urban	Netherlands	(Stobbelaar et al., 2021)
S 8	Urban	Italy	(Bottero et al., 2023)
		Poland	(Burszta-Adamiak et al., 2023)
S 11	Agriculture	Austria	(Aust et al., 2020)
S 12	Agriculture	Austria	(Aust et al., 2020)
T 1	Urban	Relevant everywhere	(Paul & Rakshit, 2022)
T 15	Agriculture	Spain	(Navarro Pedreño et al., 2012)
T 16	Urban	Italy	(Ciriminna et al., 2022; Fini et al., 2017)
T 18	Agriculture	Spain	(Navarro Pedreño et al., 2012)
T 21	Urban	Relevant everywhere	(Paul & Rakshit, 2022)
T 22	Urban	EU	(EC, 2012)
T 25	Urban	Relevant everywhere	(Ooi et al., 2022)
T 26	Urban	Italy	(Bottero et al., 2023)

3.2.6 Soil pollution

Pollution is defined by the European Commission's (EC) Industrial Emission Directive ("2010/75/EU ") as 'Direct or indirect introduction, as a result of human activity, of substances, vibrations, heat or noise into air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment'. When it comes to soil and land, contamination is a more common concept defined in the EEA glossary as 'Introduction into or onto water, air, soil or other media of microorganisms, chemicals, toxic substances, wastes, wastewater or other pollutants in a concentration that makes the medium unfit for its next intended use' (EEA, 2024). For this literature review pollution or contamination has been taken into account as a state. Air pollution or emission have also been investigated but as a driver that induces soil pollution. SMS ontology report (Nougues & Brils, 2023) is used to source the definition for soil pollution and should be used to for the description of the associated terminologies. Table 10 summarises the information from the literature that have specifically, but not limited to, referred to soil pollution as per definitions and the associated drivers. The associated drivers presented in Table 10 are referred to in short code together with the location and the reference sources.

Table 10: List of drivers relevant for soil pollution

Short code	Land use	Location	Citation
D 1	Agriculture	Spain	(Bruno et al., 2021)
D 9	Agriculture	Relevant everywhere	(Abrol & Shankar, 2014)
	Nature	Germany	(Klaus et al., 2018)
E 1	Agriculture	Relevant everywhere	(Barbosa et al., 2018)
		Ukraine	(Ryabchenko & Nonhebel, 2016)
		EU	(Pivato et al., 2016)
E 3	Agriculture	Relevant everywhere	(Kourgialas, 2021)
E 6	Agriculture	Relevant everywhere	(Kourgialas, 2021; Pereira et al., 2020)
	Urban	Relevant everywhere	(Tóth et al., 2021)
		Hungary	(Tóth et al., 2023)
E 7	Agriculture	Relevant everywhere	(Abrol & Shankar, 2014; Fowler et al., 2015; Kourgialas, 2021)
		Ukraine	(Ryabchenko & Nonhebel, 2016)
E 17	Urban	Czech republic	(Drahota et al., 2018)
N 2	Agriculture	Relevant everywhere	(Fowler et al., 2015)
	Urban	Relevant everywhere	(Vasenev et al., 2017)
N 5	Agriculture	Relevant everywhere	(Kourgialas, 2021)
N 6	Agriculture	Relevant everywhere	(Kourgialas, 2021)
	Nature	Netherlands	(Kopittke et al., 2012)
N 9	Nature	Netherlands	(Hoogland et al., 2012)
P 7	Agriculture	EU	(P. Panagos, A. Muntwyler, et al., 2022)
	Agriculture	Italy	(Ricci et al., 2022)

	Agriculture	Relevant everywhere	(Gianico et al., 2021)
P 8	Agriculture	EU	(Orgiazzi et al., 2022)
	Urban	EU	("COM(2021) 400 final," 2021)
P 9	Agriculture	EU	(Orgiazzi et al., 2022)
P 10	Agriculture	EU	(Orgiazzi et al., 2022)
P 11	Agriculture	EU	(Rodríguez et al., 2022)
P 15	Agriculture	EU	(Braguglia et al., 2015; Gianico et al., 2021)
		Spain	(Marguí et al., 2016)
		Sweden	(Kirchmann et al., 2017)
	Urban	EU	("86/278/EEC," 1986)
P 16	Urban	EU	("98/15/EC," 1998)
P 20	Agriculture	EU	(Barbosa et al., 2018)
		Germany	(Bunzel et al., 2014)
P 23	Agriculture	Germany	(Bunzel et al., 2014)
P 24	Agriculture	EU	(Levers et al., 2016)
		Portugal	(Cameira et al., 2019)
P 27	Urban	EU	(EC, 2023c)
P 37	Urban	Relevant everywhere	("COM(2021) 699 final," 2021)
P 43	Agriculture	EU	(Gianico et al., 2021)
S 4	Agriculture	EU	(Saget et al., 2020)
S 6	Agriculture	Denmark	(Case et al., 2017)
T 1	Forest	EU	(Bommarez et al., 2021; Waldner et al., 2014)
		Germany	(Wellmitz et al., 2023)
		Relevant everywhere	(Forsius et al., 2021; Grennfelt et al., 2020)
	Urban	Greece	(Alexakis et al., 2021)
		Poland	(Bielińska et al., 2018)
		Spain	(Carrero et al., 2013)
		Hungary	(Horváth et al., 2021)
		Relevant everywhere	(Lacalle et al., 2018; Petrova et al., 2022; Vasenev et al., 2017)
		France	(Le Guern et al., 2018)
T 2	Agriculture	Europe	(Horton et al., 2017)
		Spain	(Marguí et al., 2016)
		EU	(Rodríguez et al., 2022)
		Relevant everywhere	(Gianico et al., 2021; Wong et al., 2020)
		Sweden	(Kirchmann et al., 2017)
	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 5	Forest	EU	(Bommarez et al., 2021)
T 6	Agriculture	Europe	(Horton et al., 2017)
		Spain	(Rodríguez et al., 2022)
		Relevant everywhere	(Wong et al., 2020)
T 8	Agriculture	Sweden	(Kirchmann et al., 2017)
	Urban	Portugal	(Cachada et al., 2012)
		Relevant everywhere	(FAO & UNEP, 2021)
T 9	Urban	Spain	(Florido et al., 2011)

		Relevant everywhere	(Webb et al., 2018)
T 11	Agriculture	Relevant everywhere	(Kourgialas, 2021)
T 12	Agriculture	EU	(Orgiazzi et al., 2022; Rodríguez et al., 2022)
T 13	Agriculture	Sweden	(Kirchmann et al., 2017)
	Urban	EU	(Dajić et al., 2016)
T 17	Agriculture	Greece	(Papadopoulos et al., 2011)
		EU	(Orgiazzi et al., 2022)
T 19	Agriculture	EU	(Orgiazzi et al., 2022)
T 20	Agriculture	EU	(P. Panagos, A. Muntwyler, et al., 2022)
		Italy	(Ricci et al., 2022)
T 21	Agriculture	Germany	(Henseler et al., 2022)
		EU	(Braguglia et al., 2015; Piveteau et al., 2022)
		Europe	(Horton et al., 2017)
		Spain	(Marguí et al., 2016; Martínez-Cortijo & Ruiz-Canales, 2018)
		Italy	(Pivato et al., 2016)
		Relevant everywhere	(Gianico et al., 2021; Shahane & Shivay, 2021; Wong et al., 2020)
		Denmark	(Case et al., 2017)
		Sweden	(Kirchmann et al., 2017)
T 23	Urban	Relevant everywhere	(Petrova et al., 2022)
T 24	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018; Malone et al., 2023)
		Europe	(Panagos et al., 2013)
T 25	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 27	Urban	Relevant everywhere	(Petrova et al., 2022)
T 28	Agriculture	Greece	(Papadopoulos et al., 2011)
T 29	Agriculture	Relevant everywhere	(Arenas-Montaño et al., 2021)
		Sweden	(Kirchmann et al., 2017)

3.2.7 Soil erosion

Soil erosion is appropriated for this literature review according to the definition provided by European Soil Data Centre (ESDAC) as 'The wearing away of the land surface by water, wind, ice, gravity or other natural or anthropogenic agents that abrade, detach and remove soil particles or rock material from one point on the earth's surface, for deposition elsewhere, including gravitational creep and so-called tillage erosion' (ESDAC, 2024). Soil erosion is a well-established topic, reflected in the literature search. SMS ontology report (Nougues & Brils, 2023) is used to source the definition for soil erosion and should be used to for the description of the associated terminologies such as wind erosion, surface runoff, etc. Table 11 summarises the information from the literature that have specifically, but not limited to, referred to soil erosion as per definition and the associated drivers. The associated drivers in Table 11 are referred to in short code followed by the location and the source references.

Table 11: List of drivers relevant for soil erosion

Short code	Land use	Location	Citation
D 1	Agriculture	Spain	(García-Ruiz, 2010)
	Nature	Portugal	(Carvalho-Santos et al., 2019; Nunes et al., 2011)
		Italy	(Reichenbach et al., 2014)
		Mediterranean	(Shakesby, 2011)
D 3	Agriculture	Spain	(Cerdà et al., 2019)
D 6	Agriculture	Portugal	(Jones, 2016)
E 1	Agriculture	Relevant everywhere	(Andrea et al., 2018; Lal, 2010)
		EU	(Zegada-Lizarazu & Monti, 2011)
		Spain	(Vargas-Amelin & Pindado, 2014)
E 3	Forest	Poland	(Sikorski et al., 2013)
	Nature	Relevant everywhere	(Hinkel et al., 2013)
E 4	Agriculture	Drylands	(Bisaro et al., 2014)
E 6	Agriculture	Relevant everywhere	(Pereira et al., 2020)
		Europe	(Thapa et al., 2021)
E 7	Agriculture	Spain	(Rubio-Delgado et al., 2019; Vargas-Amelin & Pindado, 2014)
E 11	Agriculture	Drylands	(Bisaro et al., 2014)
	Nature	Portugal	(Nunes et al., 2011)
E 12	Agriculture	Mediterranean	(Cerdà et al., 2019)
E 14	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
E 15	Agriculture	Italy	(Debolini et al., 2015)
N 1	Nature	Italy, Switzerland	(Maruffi et al., 2022)
N 2	Nature	Switzerland	(Braun et al., 2019)
N 3	Agriculture	France, Germany, Italy, Spain, Bulgaria, Portugal	(Borrelli et al., 2023)
N 3	Agriculture	Greece	(P. Panagos, P. Borrelli, et al., 2022)
		Hilly and mountainous region	(Tarolli & Straffelini, 2020)
		Relevant everywhere	(Jones, 2016)

	Nature	Switzerland	(Braun et al., 2019)
		Hungary	(Keller et al., 2019)
		Serbia	(Perović et al., 2019)
N 5	Agriculture	Mediterranean	(Borrelli et al., 2023)
		Spain	(Marques et al., 2015)
		Relevant everywhere	(Jones, 2016; Schultz & Stoll, 2010)
		Hungary	(Mezosi et al., 2016)
		EU	(Panagos & Katsoyiannis, 2019)
		Italy	(Samela et al., 2022)
	Nature	Italy	(Berteni & Grossi, 2020)
		Portugal	(Carvalho et al., 2023; Follmi et al., 2022)
		Europe	(Maetens et al., 2012; Panagos et al., 2017; Podmanicky et al., 2011; Polce et al., 2016)
		Romania	(Patriche, 2023)
		Greece	(Polykretis et al., 2023)
		Slovakia	(Rončák & Šurda, 2019)
		Mediterranean	(Shakesby, 2011)
		Italy	(Stanchi et al., 2013)
		Greece	(Stefanidis et al., 2021)
	Urban	Relevant everywhere	(Bullock, 2005)
		Germany	(Gericke et al., 2019)
N 6	Agriculture	Norway	(Deelstra et al., 2011)
		Relevant everywhere	(Jones, 2016)
		EU	(Panagos & Katsoyiannis, 2019)
		Italy	(Samela et al., 2022)
		Portugal	(C. S. S. Ferreira et al., 2018)
	Nature	Portugal	(Esteves et al., 2012)
		Slovakia	(Földes et al., 2020)
		Germany	(Gericke et al., 2019)
N 7	Agriculture	Finland	(Rankinen et al., 2013)
N 8	Nature	Germany	(Naipal et al., 2020)
N 9	Nature	Relevant everywhere	(Hinkel et al., 2013)
		Baltic region	(Schibalski et al., 2022)
N 10	Agriculture	Finland	(Rankinen et al., 2013)
	Nature	Europe	(Verburg et al., 2012)
P 3	Agriculture	EU	(Panagos & Katsoyiannis, 2019)
	Nature	Relevant everywhere	(Borrelli et al., 2017)
		Greece	(Stefanidis et al., 2021)
P 7	Agriculture	EU	(Panagos & Katsoyiannis, 2019)
		Italy	(Ricci et al., 2022)
P 9	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
		Portugal	(C. S. S. Ferreira et al., 2018)
P 20	Agriculture	Italy	(Bazzoffi & Gardin, 2011; Borrelli et al., 2016)
		EU	(Borrelli et al., 2023; Panagos et al., 2016; Panagos & Katsoyiannis, 2019; Rajbanshi et al., 2023)
		Spain	(Vargas-Amelin & Pindado, 2014)

		Italy	(Debolini et al., 2015)
	Nature	Greece	(Kosmas et al., 2015; Stefanidis et al., 2021)
		Portugal	(Nunes et al., 2011)
P 23	Agriculture	EU	(Zegada-Lizarazu & Monti, 2011)
P 25	Agriculture	Portugal	(C. S. S. Ferreira et al., 2018)
P 26	Agriculture	Italy	(Debolini et al., 2015)
P 30	Agriculture	Switzerland	(Prasuhn, 2020)
P 31	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
S 4	Nature	Relevant everywhere	(Borrelli et al., 2017)
S 5	Agriculture	Spain	(Alatorre et al., 2012)
	Nature	Italy	(Bordoni et al., 2020)
		Germany	(Kaiser et al., 2020)
		Hungary	(Keller et al., 2019)
		Belgium	(Notebaert et al., 2011)
		Europe	(Polce et al., 2016)
		Spain	(Ries, 2010)
S 6	Agriculture	Spain	(Marques et al., 2015)
		Relevant everywhere	(Turck et al., 2023)
		Netherlands	(Norris et al., 2021)
		Switzerland	(Prasuhn, 2020)
S 7	Agriculture	Spain	(Marques et al., 2015)
S 8	Agriculture	Switzerland	(Prasuhn, 2020)
	Nature	Spain	(Cantón et al., 2011)
		Relevant everywhere	(Poesen, 2018)
		Italy	(Romano et al., 2018)
S 12	Nature	Relevant everywhere	(Otte et al., 2012)
T 3	Agriculture	Spain	(García-Ruiz, 2010)
T 3	Agriculture	Hilly and mountainous region	(Tarolli & Straffelini, 2020)
		EU	(Mezosi et al., 2016)
		Switzerland	(Prasuhn, 2020)
T 6	Agriculture	EU	(Mezosi et al., 2016)
	Forest	Finland	(Piirainen et al., 2007)
T 10	Agriculture	Spain	(Marques et al., 2015; Vargas-Amelin & Pindado, 2014)
		Relevant everywhere	(Schultz & Stoll, 2010)
T 11	Agriculture	Italy	(Abdelwahab et al., 2016)
		Relevant everywhere	(Halecki et al., 2018; Schultz & Stoll, 2010)
		Spain	(Vargas-Amelin & Pindado, 2014)
	Urban	Serbia	(Ristic et al., 2011)
T 12	Agriculture	Czech republic	(Žížala et al., 2017)
	Agriculture	Italy	(Samela et al., 2022)
T 15	Agriculture	EU	(Efthimiou et al., 2022; Panagos & Katsoyiannis, 2019)

		Relevant everywhere	(Halecki et al., 2018; Schultz & Stoll, 2010)
		Czech republic	(Žížala et al., 2017)
		Italy	(Samela et al., 2022)
T 17	Agriculture	EU	(Panagos & Katsoyiannis, 2019)
T 18	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
T 20	Agriculture	Relevant everywhere	(Jones, 2016; Rajbanshi et al., 2023; Schultz & Stoll, 2010; Shahane & Shivay, 2021)
		EU	(Panagos & Katsoyiannis, 2019; Zegada-Lizarazu & Monti, 2011)
		Spain	(Vargas-Amelin & Pindado, 2014)
		Italy	(Ricci et al., 2022)
		Switzerland	(Prasuhn, 2020)
		Portugal	(C. S. S. Ferreira et al., 2018)
T 22	Nature	Italy	(Bordoni et al., 2023)
		Portugal	(Esteves et al., 2012)
	Urban	Relevant everywhere	(Du et al., 2022)
T 25	Agriculture	Germany	(Frank et al., 2014)

3.2.8 Soil structure

Soil structure, as well as soil biodiversity, is appropriated for this literature review according to the definition provided by the ISO standard (ISO, 2015), as ´Arrangement of particles and organic matter to form aggregates which produce macro structures and micro structures in the soil´. Soil structure is combined with soil biodiversity as an EU soil mission objective, but in the SOLO work packages, soil structure and soil biodiversity are individually explored. SMS ontology report (Nougues & Brils, 2023) is used to source the definition for soil structure and should be used for the description of the associated terminologies. Soil structure is a relatively less explored topic in literature but still, certain relevant literature for different locations corroborating to different land uses have been identified. Table 12 summarises the information from the literature that have specifically, but not limited to, referred to soil structure as per definitions and the associated drivers. The associated drivers are referred to in short code followed by the location and the source references.

Table 12: List of drivers relevant for soil structure

Short code	Land use	Location	Citation
D 2	Agriculture	Italy	(C. S. S. Ferreira et al., 2018)
D 9	Agriculture	Not sure	(Blum, 2013)
E 1	Agriculture	EU	(Zegada-Lizarazu & Monti, 2011)
E 6	Agriculture	Relevant everywhere	(Pereira et al., 2020)
E 11	Agriculture	Spain	(Parras-Alcántara et al., 2013)
E 12	Agriculture	Mediterranean	(Cerdà et al., 2019)
E 13	Agriculture	Spain	(González-Rosado et al., 2023; Parras-Alcántara et al., 2013)
P 20	Agriculture	Spain	(Parras-Alcántara et al., 2013)
		Sweden	(Josefsson et al., 2017)
P 23	Agriculture	EU	(Zegada-Lizarazu & Monti, 2011)
S 5	Agriculture	Relevant everywhere	(Dangal et al., 2022)
S 6	Agriculture	Denmark	(Case et al., 2017)
S 7	Agriculture	Spain	(González-Rosado et al., 2023)
T 3	Forest	Italy	(Blasi et al., 2013)
		Finland	(Toivio et al., 2017)
		France	(Mohieddinne et al., 2022)
T 6	Forest	Italy	(Blasi et al., 2013)
		Norway	(Huusko et al., 2015)
		France	(Mohieddinne et al., 2022)
T 7	Urban	Poland	(Greinert, 2015)
T 10	Urban	Mediterranean	(Seifollahi-Aghmiuni et al., 2022)
T 12	Forest	France	(Mohieddinne et al., 2022)
T 15	Forest	France	(Mohieddinne et al., 2022)
T 20	Agriculture	Relevant everywhere	(Shahane & Shivay, 2021)
		EU	(Zegada-Lizarazu & Monti, 2011)
T 21	Agriculture	Relevant everywhere	(Shahane & Shivay, 2021)
		Denmark	(Case et al., 2017)

3.2.9 Soil biodiversity

Soil biodiversity is appropriated for this literature review according to the definition provided by the ISO standard (ISO, 2015) for soil quality which also provides the criteria for soil biodiversity monitoring and measurement. It is defined as 'Variability among living organisms on the earth, including the variability within and between species, and within and between ecosystems' (ISO, 2015). And for monitoring, it states, 'Soil biodiversity may be measured and monitored by collecting soil samples and extracting soil animals (or DNA) to identify the different groups of organisms and it is also possible to monitor biological activities (e.g. enzymatic measurements, organic matter degradation)' (ISO, 2015). Soil biodiversity, however, is not explicitly mentioned as an EU soil mission objective, rather it is combined with soil structure. Soil structure (see section 3.3.5) and soil biodiversity are individually explored in the literature to support the separate think tanks established as part of SOLO. SMS ontology report (Nougues & Brils, 2023) is used to source the definition for soil biodiversity and should be used to for the description of the associated terminologies. Table 13 summarises the information from the literature that have specifically, but not limited to, referred to soil biodiversity as per definitions and the associated drivers. The associated drivers in the table are referred to in short code, followed by the location and the source references.

Table 13: List of drivers relevant for soil biodiversity

Short code	Land use	Location	Citation
D 9	Agriculture	Relevant everywhere	(Gomiero et al., 2011; Siebert et al., 2020)
E 1	Agriculture	EU	(Pivato et al., 2016; Zegada-Lizarazu & Monti, 2011)
		Spain	(Vargas-Amelin & Pindado, 2014)
	Forest	Sweden	(Ebenhard et al., 2017)
E 3	Forest	Poland	(Sikorski et al., 2013)
E 6	Agriculture	Europe	(Thapa et al., 2021)
	Urban	Relevant everywhere	(Tóth et al., 2021)
	Urban	Hungary	(Tóth et al., 2023)
E 7	Agriculture	Relevant everywhere	(Gomiero et al., 2011; Siebert et al., 2020)
		Spain	(Vargas-Amelin & Pindado, 2014)
	Nature	Germany	(Boeddinghaus et al., 2019; Herold et al., 2014)
E 11	Agriculture	EU	(Zander et al., 2016)
E 13	Agriculture	Relevant everywhere	(Schütte et al., 2017)
		EU	(Zander et al., 2016)
		Spain	(Fernández-Guisuraga et al., 2022)
E 14	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
	Forest	Sweden	(Redondo et al., 2018)
E 16	Forest	Sweden	(Redondo et al., 2018)
N 1	Forest	Relevant everywhere	(Meena et al., 2023)
N 2	Agriculture	Germany	(Siebert et al., 2019)
	Forest	Relevant everywhere	(Meena et al., 2023)
		Germany	(Englmeier et al., 2022)
	Nature	Europe	(Fagúndez, 2013)

		France	(Mony et al., 2022)
		Denmark	(Reinsch et al., 2013)
N 5	Agriculture	Germany	(Siebert et al., 2019)
	Forest	Relevant everywhere	(Meena et al., 2023)
	Nature	Netherlands	(Dias et al., 2013)
		Switzerland	(Midolo et al., 2021)
		Relevant everywhere	(Yin et al., 2019)
N 6	Agriculture	Relevant everywhere	(Siebert et al., 2020)
	Forest	Relevant everywhere	(Meena et al., 2023)
		Portugal	(Camacho et al., 2018)
		Sweden	(Redondo et al., 2018)
	Nature	Sweden	(Brangarí et al., 2022)
N 7	Agriculture	Sweden, Finland, Norway, Denmark	(Unc et al., 2021)
N 11	Nature	Germany	(Herold et al., 2014)
N 12	Agriculture	Relevant everywhere	(Schütte et al., 2017)
P 7	Agriculture	EU	(Orgiazzi et al., 2022)
P 8	Agriculture	EU	(Orgiazzi et al., 2022)
P 9	Agriculture	EU	(Orgiazzi et al., 2022)
		Spain	(Vargas-Amelin & Pindado, 2014)
	Nature	Relevant everywhere	(Hák et al., 2016)
P 10	Agriculture	EU	(Orgiazzi et al., 2022)
	Nature	Italy	(Farris et al., 2010)
	Urban	EU	(EU, 2021)
P 11	Agriculture	EU	(Rodríguez et al., 2022)
P 12	Forest	Sweden	(Ebenhard et al., 2017)
P 13	Nature	Estonia	(Leppik et al., 2015)
P 14	Forest	Sweden	(Ebenhard et al., 2017)
P 20	Agriculture	Portugal	(Jones et al., 2011)
		Sweden	(Josefsson et al., 2017)
		Netherlands	(Norris et al., 2021)
		EU	(Zander et al., 2016)
		Spain	(Fernández-Guisuraga et al., 2022; Vargas-Amelin & Pindado, 2014)
P 21	Agriculture	Germany	(Renwick et al., 2013)
P 22	Agriculture	Portugal	(Jones et al., 2011)
	Forest	Sweden	(Ebenhard et al., 2017)
P 23	Agriculture	EU	(Zegada-Lizarazu & Monti, 2011)
P 31	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
P 39	Agriculture	Portugal	(Jones et al., 2011)
P 43	Agriculture	Sweden, Finland, Norway, Denmark	(Unc et al., 2021)
S 5	Agriculture	Spain	(Archidona-Yuste et al., 2021)
		Belgium	(De Schrijver et al., 2012)
	Nature	Sweden	(Bahr et al., 2012)
		Portugal	(Costa et al., 2013)

		Estonia	(Leppik et al., 2013, 2015)
		France	(Mony et al., 2022; Pansu et al., 2015)
		Germany	(Estendorfer et al., 2017; Schrautzer et al., 2016; Socher et al., 2012)
S 5	Nature	Not sure	(Vasileiadis et al., 2013)
S 6	Agriculture	EU	(Zander et al., 2016)
S 7	Agriculture	EU	(Zander et al., 2016)
S 11	Forest	Relevant everywhere	(Meena et al., 2023)
T 2	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 3	Forest	Italy	(Blasi et al., 2013)
T 5	Nature	Europe	(Fagúndez, 2013)
T 5	Nature	Germany	(Heinze et al., 2015)
T 6	Agriculture	Spain	(Archidona-Yuste et al., 2021; Rodríguez et al., 2022)
		Relevant everywhere	(Schütte et al., 2017)
		Germany	(Siebert et al., 2020; Siebert et al., 2019)
	Forest	Italy	(Blasi et al., 2013)
		Norway	(Huusko et al., 2015)
		Relevant everywhere	(Frac et al., 2018)
	Nature	Germany	(Heinze et al., 2015)
		Austria, France	(Szukics et al., 2019)
T 10	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
T 11	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
T 12	Agriculture	EU	(Orgiazzi et al., 2022; Rodríguez et al., 2022)
		Latvia	(Stals & Ivanovs, 2019)
	Forest	Relevant everywhere	(Arias et al., 2005; Meena et al., 2023)
T 15	Agriculture	Latvia	(Stals & Ivanovs, 2019)
T 17	Agriculture	EU	(Orgiazzi et al., 2022)
	Forest	Relevant everywhere	(Arias et al., 2005; Frac et al., 2018)
T 18	Agriculture	Spain	(Vargas-Amelin & Pindado, 2014)
T 19	Agriculture	EU	(Orgiazzi et al., 2022)
T 20	Agriculture	Relevant everywhere	(Bach et al., 2020; Kammann et al., 2017; Shahane & Shivay, 2021)
		Spain	(Moreno-García et al., 2021; Vargas-Amelin & Pindado, 2014)
		EU	(Zegada-Lizarazu & Monti, 2011)
		Switzerland	(Yang et al., 2021)
T 21	Agriculture	Italy	(Pivato et al., 2016)
		Relevant everywhere	(Shahane & Shivay, 2021)
T 24	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 25	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 26	Forest	Spain	(Barberá et al., 2019)

T 26	Forest	Relevant everywhere	(Korboulewsky et al., 2016; Meena et al., 2023)
T 26	Forest	Slovakia	(Bobuľská et al., 2019)
T 29	Agriculture	Relevant everywhere	(Kammann et al., 2017)

3.2.10 EU global footprint on soil

EU global footprint is appropriated in this literature review as' 'EU's Ecological Footprint compared to that of the world' (Nougues & Brils, 2023). An ecological footprint is explained in the SMS ontology report (Nougues & Brils, 2023) as 'the only metric that compares the resource demand of individuals, governments, and businesses against Earth's capacity for biological regeneration'. The SMS ontology report (Nougues & Brils, 2023) is used to source the definition EU global footprint on soil and should be used for the description of the associated terminologies. EU global footprint on soil is not explored in the literature as phrased in the texts. But many associated concepts are explored in the literature as suggested by the definition, which can be attributed to this topic. The topics and concepts that are considered within its scope are for example, changes in demand, changes in dietary habits, increasing demand or production of renewable or bio-based energy or products, or any topics related to impact global greenhouse gas (GHG) emission. Table 14 summarises the information from the literature that have specifically, but not limited to, been interpreted as referring to EU global footprint on soil as per definitions and the associated drivers. The associated drivers presented in Table 14 are referred to in short code followed by the location and the source references.

Table 14: List of drivers relevant for EU global footprint on soil

Short code	Land use	Location	Citation
D 9	Agriculture	Spain	(Jeong, 2018)
		Mediterranean	(Scordia et al., 2020)
E 1	Agriculture	Relevant everywhere	(Bonin & Lal, 2012; Drewer et al., 2016; Haughey et al., 2023)
		EU	(Pivato et al., 2016; Solinas et al., 2021; Zegada-Lizarazu & Monti, 2011)
		Mediterranean	(Scordia et al., 2020)
		Italy	(Serra et al., 2017)
	Forest	Sweden	(Ebenhard et al., 2017)
E 4	Agriculture	EU	(Smith, 2012)
		France	(Bamière et al., 2023)
E 7	Agriculture	Relevant everywhere	(Fowler et al., 2015; Gomiero et al., 2011; Haughey et al., 2023; Smerald et al., 2022)
		Mediterranean	(Scordia et al., 2020)
E 11	Agriculture	Spain	(Parras-Alcántara et al., 2013)
		EU	(Zander et al., 2016)
E 13	Agriculture	Spain	(Jeong, 2018; Pardo et al., 2016; Parras-Alcántara et al., 2013)
		EU	(Zander et al., 2016)
N 1	Agriculture	EU	(Bais-Moleman et al., 2019)
		Relevant everywhere	(Hastings et al., 2013)
		Mediterranean	(Solinas et al., 2021)
N 2	Agriculture	Relevant everywhere	(Fowler et al., 2015; Haughey et al., 2023; Kammann et al., 2017)
N 2	Agriculture	EU	(Vanino et al., 2018)
		Europe	(Carrer et al., 2018)
N 5	Agriculture	Spain	(Jeong, 2018; Pardo et al., 2016)
		Mediterranean	(Scordia et al., 2020)
N 6	Agriculture	Spain	(Pardo et al., 2016)
		Mediterranean	(Scordia et al., 2020)

N 7	Agriculture	Sweden, Finland, Norway, Denmark	(Unc et al., 2021)
P 3	Agriculture	Relevant everywhere	(Haughey et al., 2023)
P 5	Agriculture	France	(Bamière et al., 2023)
P 7	Agriculture	Italy	(Ricci et al., 2022)
P 12	Agriculture	France	(Bamière et al., 2023)
P 17	Urban	EU	("2010/75/EU ", 2010)
P 20	Agriculture	EU	(Kolasa-Więcek, 2015; Lugato et al., 2017; Zander et al., 2016)
		Spain	(Parras-Alcántara et al., 2013)
P 22	Agriculture	EU	(Warner et al., 2016)
P 23	Agriculture	EU	(Drewer et al., 2016; Dufossé et al., 2014; Zegada-Lizarazu & Monti, 2011)
		Italy	(Serra et al., 2017)
P 24	Agriculture	EU	(Kolasa-Więcek, 2015)
P 25	Agriculture	EU	(Kolasa-Więcek, 2015; Kourgialas, 2021)
P 33	Agriculture	France	(Bamière et al., 2023)
P 43	Agriculture	Sweden, Finland, Norway, Denmark	(Unc et al., 2021)
S 4	Agriculture	EU	(Bais-Moleman et al., 2019; Saget et al., 2020; Zander et al., 2016)
S 5	Agriculture	Germany	(Beyer et al., 2015)
		Relevant everywhere	(Haughey et al., 2023)
		EU	(Zander et al., 2016)
		Denmark	(Case et al., 2017)
S 11	Agriculture	Relevant everywhere	(Dumont et al., 2019)
T 3	Forest	EU (Temparate, Boreal)	(Barberá et al., 2019)
T 5	Forest	EU (Temparate, Boreal)	(Barberá et al., 2019)
T 6	Agriculture	France	(Drewer et al., 2016; Dufossé et al., 2014)
	Forest	EU (Temparate, Boreal)	(Barberá et al., 2019)
T 12	Agriculture	EU	(Lugato et al., 2017; Peng et al., 2015; Revill et al., 2013)
		Relevant everywhere	(Petropoulos et al., 2015; Weiss et al., 2020)
		Italy	(Vanino et al., 2018)
T 15	Agriculture	EU	(Lugato et al., 2017; Peng et al., 2015; Revill et al., 2013)
		Spain	(Pardo et al., 2016)
		Relevant everywhere	(Petropoulos et al., 2015; Weiss et al., 2020)
		Italy	(Vanino et al., 2018)
T 17	Agriculture	EU	(Lugato et al., 2017)
		Relevant everywhere	(Mueller et al., 2010)
		Greece	(Papadopoulos et al., 2011)
T 20	Agriculture	Peatland	(Bianchi et al., 2021)

		Relevant everywhere	(Haughey et al., 2023; Kammann et al., 2017)
		Spain	(Pardo et al., 2016)
		Mediterranean	(Scordia et al., 2020)
		EU	(Smith, 2012; Solinas et al., 2021; Zegada-Lizarazu & Monti, 2011)
		Germany	(Tanneberger et al., 2020)
		France	(Bamière et al., 2023)
		Europe	(Carrer et al., 2018)
		Italy	(Ricci et al., 2022)
T 21	Agriculture	Italy	(Pivato et al., 2016)
		Relevant everywhere	(Shahane & Shivay, 2021)
		Denmark	(Case et al., 2017)
T 23	Agriculture	Spain	(Jeong, 2018)
T 28	Agriculture	Greece	(Anestis et al., 2015; Papadopoulos et al., 2011)
		Relevant everywhere	(Weiss et al., 2020)
T 29	Agriculture	Relevant everywhere	(Arenas-Montaño et al., 2021; Kammann et al., 2017)

3.2.11 Soil literacy

Soil literacy is appropriated for this literature review according to the definition provided by the EC (2021) as 'The state of knowing about or being familiar with soil. It concerns both a popular awareness about the importance of soil, and specialised and practice-oriented knowledge related to achieving soil health'. SMS ontology report (Nougues & Brils, 2023) is used to source the definition for soil literacy and should be used to for the description of the associated terminologies. Soil literacy is a relatively less well explored topic as in, the phrase soil literacy has not been present in many references but many forms of it, as per the definition, has been explored in the literature for example, tools and models, systems, or methods for better understanding and procurement or transfer of soil related information and data. Table 15 summarises the information from the literature that have specifically, but not limited to, can be interpreted as referring to soil literacy as per definitions and the associated drivers. The associated drivers presented in Table 15 are referred to in short code followed by the location and the reference sources.

Table 15: List of drivers relevant for soil literacy

Short code	Land use	Location	Citation
E 11	Urban	Italy	(Calzolari et al., 2020)
		Relevant everywhere	(FAO, 2023; Head et al., 2020; O'Riordan et al., 2021)
		Romania	(Mitincu et al., 2023)
		EU	(Löbmann et al., 2022)
E 5	Urban	Relevant everywhere	(Head et al., 2020; Ilieva et al., 2022)
N 1	Forest	Relevant everywhere	(Meena et al., 2023; Nandal et al., 2023)
	Nature	Relevant everywhere	(Sardans & Peñuelas, 2014; Tuomi et al., 2011)
N 2	Forest	Relevant everywhere	(Meena et al., 2023)
N 3	Nature	Relevant everywhere	(Samariks et al., 2023)
N 5	Forest	Relevant everywhere	(Meena et al., 2023)
	Nature	France	(Romano et al., 2018)
N 6	Forest	Relevant everywhere	(Meena et al., 2023)
	Nature	Alps	(Geitner et al., 2021)
N 8	Nature	Relevant everywhere	(Samariks et al., 2023)
N 11	Nature	Relevant everywhere	(Boeddinghaus et al., 2015)
P 3	Nature	Relevant everywhere	(Weigelt et al., 2015)
P 4	Nature	Relevant everywhere	(Weigelt et al., 2015)
P 5	Forest	Relevant everywhere	(Nandal et al., 2023)
P 7	Agriculture	EU	(Orgiazzi et al., 2022)
P 8	Agriculture	EU	(Orgiazzi et al., 2022)
P 9	Agriculture	EU	(Orgiazzi et al., 2022)

	Nature	Relevant everywhere	(Lavorel et al., 2017; Samariks et al., 2023)
		Netherlands	(Rutgers et al., 2019)
P 10	Agriculture	EU	(Orgiazzi et al., 2022)
	Nature	Netherlands	(Rutgers et al., 2019)
P 11	Agriculture	EU	(Rodríguez et al., 2022)
P 15	Agriculture	Sweden	(Kirchmann et al., 2017)
P 20	Agriculture	EU	(Lugato et al., 2017)
	Nature	Relevant everywhere	(Samariks et al., 2023)
S 5	Nature	France	(Karimi et al., 2020)
		EU	(Panos Panagos et al., 2022)
		Relevant everywhere	(Sardans & Peñuelas, 2014)
S 6	Agriculture	Spain	(Marques et al., 2015)
		Denmark	(Case et al., 2017)
	Forest	Portugal, France, Czech Republic, Slovenia, Slovakia, Romania	(Feliciano et al., 2017)
		Sweden	(Degnet et al., 2022)
S 7	Agriculture	Spain	(Marques et al., 2015)
	Nature	Spain	(Cantón et al., 2011)
S 8	Forest	Relevant everywhere	(Meena et al., 2023)
S 8	Forest	Portugal, France, Czech Republic, Slovenia, Slovakia, Romania	(Feliciano et al., 2017)
	Forest	Sweden	(Degnet et al., 2022)
	Nature	France	(Ranjard et al., 2010)
		Italy	(Romano et al., 2018)
		Relevant everywhere	(Zhou et al., 2023)
S 11	Nature	Spain	(Barbero-Sierra et al., 2015)
S 11	Nature	Austria	(Minixhofer et al., 2019)
T 2	Agriculture	Sweden	(Kirchmann et al., 2017)
	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 3	Agriculture	Hilly and mountainous region	(Tarolli & Straffelini, 2020)
T 8	Agriculture	Sweden	(Kirchmann et al., 2017)
T 11	Agriculture	Relevant everywhere	(Halecki et al., 2018; Petropoulos et al., 2015; Weiss et al., 2020)
T 12	Agriculture	EU	(Lugato et al., 2017; Orgiazzi et al., 2022; Peng et al., 2015; Revill et al., 2013; Rodríguez et al., 2022)
		Latvia	(Stals & Ivanovs, 2019)
		Czech republic	(Žížala et al., 2017)
	Forest	France	(Chakir & Le Gallo, 2013)

	Forest	Relevant everywhere	(Arias et al., 2005; Meena et al., 2023; Nandal et al., 2023)
T 13	Agriculture	Sweden	(Kirchmann et al., 2017)
T 15	Agriculture	Hilly and mountainous region	(Tarolli & Straffelini, 2020)
T 15	Agriculture	EU	(Grillakis et al., 2021)
T 15	Agriculture	Relevant everywhere	(Halecki et al., 2018; Petropoulos et al., 2015; Weiss et al., 2020)
		EU	(Lugato et al., 2017; Peng et al., 2015; Revill et al., 2013)
		Latvia	(Stals & Ivanovs, 2019)
		Ukraine	(Stefanski et al., 2014)
		Czech republic	(Žížala et al., 2017)
		Italy	(Samela et al., 2022; Vanino et al., 2018)
	Forest	Relevant everywhere	(Nandal et al., 2023; Shahane & Shivay, 2021)
T 17	Agriculture	EU	(Lugato et al., 2017; Orgiazzi et al., 2022)
	Forest	Relevant everywhere	(Arias et al., 2005; Frac et al., 2018; Zornoza et al., 2015)
	Nature	EU	(Morais et al., 2016)
		Relevant everywhere	(Vanmaercke et al., 2011)
T 19	Agriculture	Relevant everywhere	(Brevik et al., 2016)
		EU	(Cesco et al., 2023; Orgiazzi et al., 2022)
T 21	Agriculture	Denmark	(Case et al., 2017)
		Sweden	(Kirchmann et al., 2017)
T 22	Nature	Italy	(Bordoni et al., 2023)
	Urban	Relevant everywhere	(O'Riordan et al., 2021)
T 23	Urban	EU	(Löbmann et al., 2022)
T 24	Urban	Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 25	Urban	Italy	(Calzolari et al., 2020)
		Relevant everywhere	(Gómez-Sagasti et al., 2018)
T 26	Forest	Relevant everywhere	(Meena et al., 2023; Nandal et al., 2023)
	Urban	Romania	(Mitincu et al., 2023)
T 27	Nature	Austria	(Haslmayr et al., 2016)
		Relevant everywhere	(Jónsson & Davíðsdóttir, 2016)
T 28	Agriculture	Relevant everywhere	(Weiss et al., 2020)
		EU	(Cesco et al., 2023)
T 29	Agriculture	Sweden	(Kirchmann et al., 2017)

3.2.12 Not sure

Table 17 presents the studies where it was unclear what soil health objectives were being refereed but it's relation to soil health was evident. The associated drivers in Table 16 are referred to in short code followed by the location and the source references. The identified drivers as well as their location and associated land uses are to be taken into consideration for all soil health objectives.

Table 16: List of drivers where specific soil health objectives

Short code	Land use	Location	Citation
D 1	Agriculture	Relevant everywhere	(Pereira et al., 2020)
D 2	Agriculture	Spain	(Perpiña Castillo et al., 2020)
D 3	Agriculture	Spain	(Cerdà et al., 2019)
D 4	Agriculture	Not sure	(Blum, 2013)
D 5	Agriculture	Spain	(Delgado-Artés et al., 2022)
D 7	Forest	EU	(Weiss et al., 2019)
D 9	Agriculture	Relevant everywhere	(Hastings et al., 2013; Levers et al., 2016; Spiertz, 2012; Stefanski et al., 2014)
		Europe	(Bedoussac et al., 2015)
		Not sure	(Blum, 2013)
E 1	Agriculture	Not sure	(Blum, 2013)
		Germany	(Tölle et al., 2014)
		Relevant everywhere	(Hastings et al., 2013; Spiertz, 2012; Stefanski et al., 2014)
		Netherlands	(Kuhlman et al., 2013)
E 11	Agriculture	Netherlands	(Kuhlman et al., 2013)
E 14	Urban	Spain	(Gonzalez & Ortega, 2013)
E 7	Agriculture	Spain	(Delgado-Artés et al., 2022)
		Relevant everywhere	(Hastings et al., 2013; Spiertz, 2012)
	Forest	Relevant everywhere	(d'Annunzio et al., 2015)
	Nature	Germany	(Keil et al., 2015)
E 9	Agriculture	Relevant everywhere	(Pereira et al., 2020)
N 1	Agriculture	Relevant everywhere	(Levers et al., 2016)
		Netherlands	(Kuhlman et al., 2013)
	Forest	Mediterranean	(David et al., 2016)
N 2	Agriculture	Relevant everywhere	(Jones, 2016; Levers et al., 2016)
		Spain	(Zapata-Sierra et al., 2022)
N 3	Nature	Italy	(Pirastru et al., 2017)
N 5	Agriculture	Spain	(Zapata-Sierra et al., 2022)
		France	(Vidal et al., 2012)
	Nature	Slovakia	(Bačová Mitková, 2020)
		Germany	(Keil et al., 2015)
		Europe	(Kempf, 2023)
N 6	Agriculture	France	(Vidal et al., 2012)
N 7	Agriculture	Sweden, Finland, Norway, Denmark	(Jones, 2016)

N 12	Forest	EU	(Santini et al., 2013)
P 1	Nature	Relevant everywhere	(Delibas et al., 2021)
P 20	Agriculture	Germany	(Gömann et al., 2011; Lupp et al., 2015)
	Forest	EU	(Weiss et al., 2019)
	Nature	Relevant everywhere	(Delibas et al., 2021)
P 23	Agriculture	Germany	(Gömann et al., 2011)
		Netherlands	(Kuhlman et al., 2013)
P 34	Agriculture	Germany	(Lupp et al., 2015)
P 36	Agriculture	Germany	(Waldhardt et al., 2010)
P 39	Agriculture	Germany	(Gömann et al., 2011)
S 3	Agriculture	Relevant everywhere	(Spiertz, 2012)
S 4	Agriculture	Relevant everywhere	(Stefanski et al., 2014)
S 5	Agriculture	Europe	(Bedoussac et al., 2015)
		Relevant everywhere	(Levers et al., 2016)
	Forest	Relevant everywhere	(d'Annunzio et al., 2015)
		EU	(Weiss et al., 2019)
S 5	Nature	Spain	(Lopez-Sangil et al., 2011)
S 6	Forest	EU	(Weiss et al., 2019)
T 3	Forest	Sweden	(Kim et al., 2021)
T 4	Forest	Sweden	(Nordfjell et al., 2010)
T 10	Agriculture	Not sure	(Blum, 2013)
	Forest	Mediterranean	(David et al., 2016)
T 11	Agriculture	Spain	(Zapata-Sierra et al., 2022)
	Nature	Relevant everywhere	(Jarvis et al., 2016)
T 20	Agriculture	Relevant everywhere	(Spiertz, 2012)
	Agriculture	Spain	(Zapata-Sierra et al., 2022)
T 26	Forest	EU	(Weiss et al., 2019)

4 Outlook for the interpretation, communication, and the future steps of the typology of drivers for soil health

This deliverable presents a rigorous meta-analysis process and the data that has been sorted out so far. The results have been presented sorted and structured, and presently it provides a vast pool of data on soil health at local and European scale for different soil health objectives with an immense collaborated effort by the WP3 partners. The data is now subjected to various types of analysis and interpretations, and work that has been done so far together with some of the future opportunities, will be reflected on in section 4.1.1. Throughout the collection and sorting of the data, various internal partner meetings and communication has taken place, as well as communication with other work packages in the SOLO project. Section 4.2.2 summarises the internal and external communication that has taken place and outlines the future opportunities. Section 4.3.3 presents the next steps and timeline, an updated version of what was communicated in Milestone 1 to provide a general outlook on how the rest of the WP3 work will be conducted.

4.1.1 Interpretation and analysis of the typology of drivers

Chapter 3 presents the typology of drivers sorted to the various soil health objectives. The data can also be sorted according to the location, i.e. EU33. For many well studied countries, that sorting indeed provides a good understanding of soil health drivers and key concerns. Figure 7 is a Sankey diagram for Sweden illustrating the drivers and the associated soil health objectives. It shows, among other things, the elevated exploration of soil biodiversity and soil literacy in literature specific to Sweden. But for many countries, there are not much or even no data available. In that case, of course, studies that have provided a European or EU, or even global perspective can be looked at. It also provides a good idea about the gap of knowledge and points to the need or scope of localising the soil health concerns. This scope is worth investing and further research, and an investigation on map based communication of the data is presently ongoing.

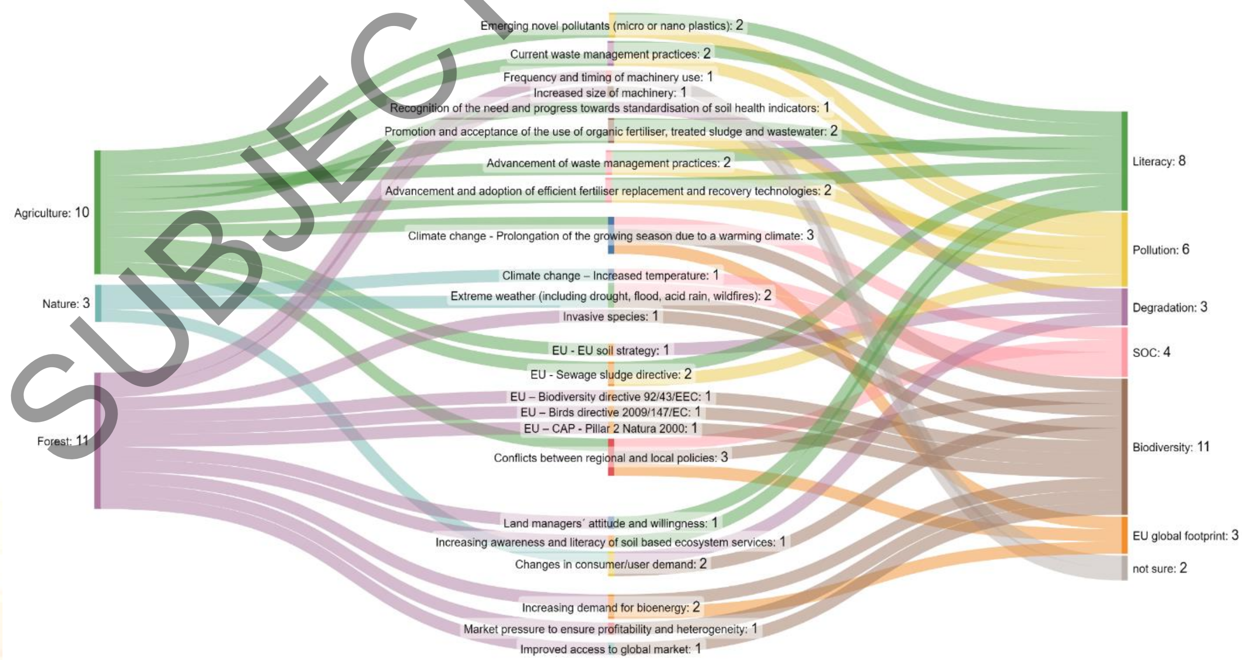

Figure 7: Drivers for soil health in Sweden

The easiest and the earliest sorting of the drivers is by land use. Figure 8 presents the general outcome of that approch. It is a good communication of the general outlook of the meta-analysis, but it lacks the depth of information present in the earlier figure (Figure 7).

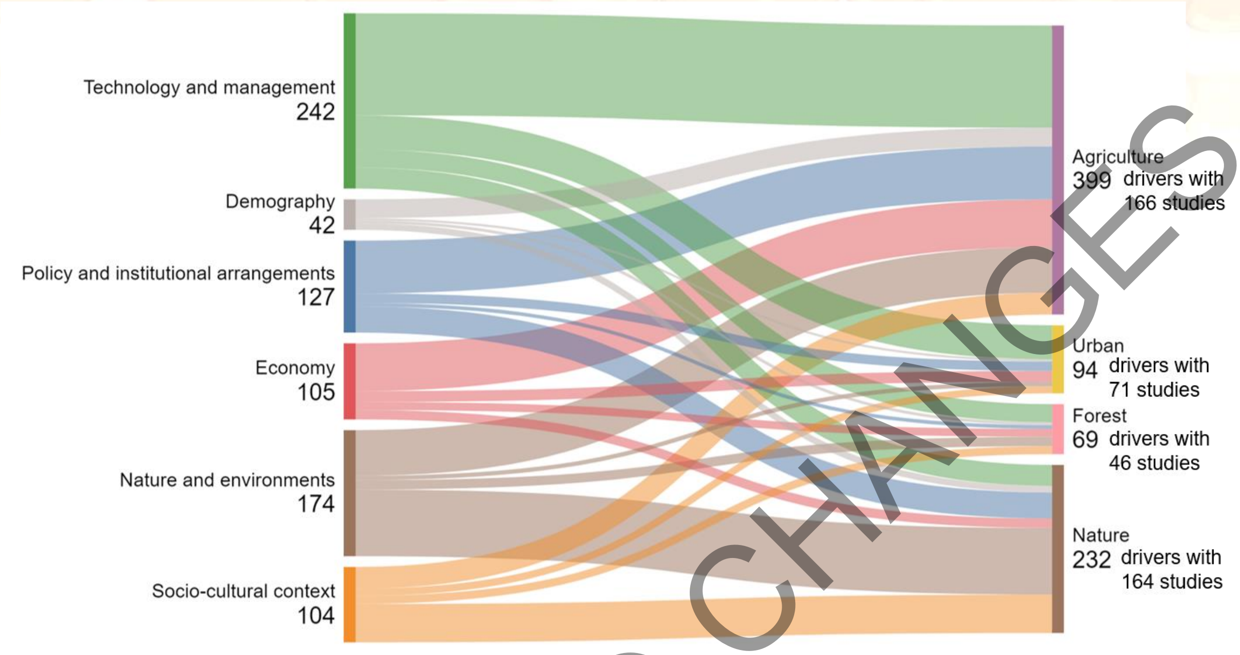

Figure 8: Numbers of drivers identified according to land uses.

As communicated before, the present sorting of the data is done to accommodate the need of the think tanks. And it is deemed a good way to scale and categorise the data that provides a general structure for future analysis and interpretation that can be communicated and interpreted by many internal and external partners.

4.1.2 Internal and external communication of the typology of drivers

The process of the planning and implementing the meta-analysis has been a collaborative effort among WP3 task leaders and partners, and frequent communication took place (see table 18 for a brief scope). All the internal communication has been recorded and the document stored and shared in the internal SOLO repository among all the other consortium partners. An early and more structured communication of the initial list of drivers took place between WP3 and WP2 (think tanks) in October 2023 during the SOLO consortium in Barcelona, to get input from the think tanks partners on the result The consolidated communication is shared as appendix 2. The summary of the state of the work was also presented during both SOLO consortium meetings held in Barcelona in 2023 and Wageningen in 2024.

To potentially have a greater impact and to realise the full potential of the sorted data, the sorted data is to be uploaded in Bonares repository, a public data repository which follows the FAIR principle and which is tailored for soil research data (https://doi.org/10.20387/zalf-a15w-f1kh). A letter from the repository explaining its credentials is attached as appendix 3. A data in brief journal is also in work to broaden the communication and scope of the results. Table 18 summarises the future scope of scientific communication regarding the WP3 work, recently updated to reflect the current progress. The result has also been presented in international conferences for increased outreach (link).

4.1.3 Next steps and timeline

The overall aim of the WP3 is not only to identify the drivers, as elaborated in this deliverable, but also to understand the dynamics within and explore the complexity it brings in regards to future changes, in terms of use and management of soil and land. Protocol M1 outlines the scope and steps to achieve this. The results presented in this deliverable is the output of the first step (outlined in detail with sub-steps in Section 2). The rest of the steps and its output are to be summarised in the final deliverable of the WP3, deliverable 3.2. The future work divided in the following steps:

- Step 2 (S2) - Driver's interactions and impacts on the soil and land use management over time
- Step 3 (S3) - Analysis of drivers and their dynamics for future changes in soil and land use management.

Presently the Step 2 has been updated Step 2 has been detailed out presently and it builds on the drivers (typology of drivers – Deliverable 3.1) to detail out the interactions and the impacts of soil and land use management over time. The step is divided in two sub-steps firstly, the identified drivers and their relationship are to be synthesise to provide an overall outlook for EU and different regions, and secondly, analysing the drivers to provide more in-depth understanding on their mechanism on impacting different soil health objectives. The work on the first part is ongoing and the result of the synthesis is to be published in a peer reviewed journal paper. The work on the second part is planned to take place in collaboration with the think tanks. As each of the think tanks were developed to represent an individual soil health objectives, engaging the expertise of the stakeholders in the think tanks would provide the much needed expert overview on the data acquired. The details on facilitating such collaboration is to be outlined in the next SOLO consortium due in November 2024.

The work on step 3 - analysis of drivers and their dynamics for future changes in soil and land use management, would require the rest of metadata to be sorted and organized. The data would connect the drivers with respective changes in use or management of land or soil, and sorting is expected to commence on December 2024. This set of data will similarly be made public like the previous using a reputable public repository. The work process further would be discussed and outlined during the next SOLO consortium due in November 2024. A timeline for the WP3 activity is provided in the deliverable 3.1 which is periodically updated. Deliverable 3.1 corroborates to the completion of Step 1 and the sub-steps within. A timeline has been set and constantly updated to plan and track the progress of the work can be found in Appendix 1. By structuring the work, the timeline also provide the scope for scientific communication and publication.

5 Acknowledgements

The present deliverable is a consolidated effort by the WP3 partners who have taken on the task to implement a systematic analysis of the literature on soil health. Many associated documents, online and offline databases, have to be maintained and constantly updated to make this deliverable possible. With good will, trust, and hard work, a vast pool of data has been established that is sound and comprehensive, and something that will continue to benefit us at SOLO and the scientific community in general, in many ways in future. We thank our partners at WP3 again for trusting the process.

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6 References

86/278/EEC, (1986).

98/15/EC, (1998).

2010/75/EU (2010).

Abdalla, M., Hastings, A., Bell, M. J., Smith, J. U., Richards, M., Nilsson, M. B., Peichl, M., Löfvenius, M. O., Lund, M., Helfter, C., Nemitz, E., Sutton, M. A., Aurela, M., Lohila, A., Laurila, T., Dolman, A. J., Belelli-Marchesini, L., Pogson, M., Jones, E., . . . Smith, P. (2014). Simulation of CO2 and Attribution Analysis at Six European Peatland Sites Using the ECOSSE Model. *Water, Air, & Soil Pollution*, *225*(11), 2182. https://doi.org/10.1007/s11270-014-2182-8

Abdelwahab, O. M. M., Milillo, F., & Gentile, F. (2016). Modeling soil erosion and sediment load at different time scales in a medium-sized watershed. 2016 American Society of Agricultural and Biological Engineers Annual International Meeting, ASABE 2016,

Abrol, D. P., & Shankar, U. (2014). Pesticides, food safety and integrated pest management. In *Integrated Pest Management: Pesticide Problems, Vol.3* (pp. 167-199). https://doi.org/10.1007/978-94-007-7796-5_7

Addai, K., Serener, B., & Kirikkaleli, D. (2022). Empirical analysis of the relationship among urbanization, economic growth and ecological footprint: evidence from Eastern Europe. *Environmental Science and Pollution Research*, *29*(19), 27749-27760. https://doi.org/10.1007/s11356-021-17311-x

Adil, M., Yao, Z., Zhang, C., Lu, S., Fu, S., Mosa, W. F. A., Hasan, M. E., & Lu, H. (2022). Climate change stress alleviation through nature based solutions: A global perspective [Review]. *Frontiers in Plant Science*, *13*, Article 1007222. https://doi.org/10.3389/fpls.2022.1007222

Aksoy, E., Gregor, M., Schröder, C., Löhnertz, M., & Louwagie, G. (2017). Assessing and analysing the impact of land take pressures on arable land [Article]. *Solid Earth*, *8*(3), 683-695. https://doi.org/10.5194/se-8-683-2017

Alatorre, L. C., Beguería, S., Lana-Renault, N., Navas, A., & García-Ruiz, J. M. (2012). Soil erosion and sediment delivery in a mountain catchment under scenarios of land use change using a spatially distributed numerical model [Article]. *Hydrology and Earth System Sciences*, *16*(5), 1321-1334. https://doi.org/10.5194/hess-16-1321-2012

Albaladejo, J., Ortiz, R., Garcia-Franco, N., Navarro, A. R., Almagro, M., Pintado, J. G., & Martínez-Mena, M. (2013). Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain. *Journal of Soils and Sediments*, *13*(2), 265-277. https://doi.org/10.1007/s11368-012-0617-7

Aldezabal, A., Moragues, L., Odriozola, I., & Mijangos, I. (2015). Impact of grazing abandonment on plant and soil microbial communities in an Atlantic mountain grassland. *Applied Soil Ecology*, *96*, 251-260. https://doi.org/https://doi.org/10.1016/j.apsoil.2015.08.013

Alexakis, D. E., Bathrellos, G. D., Skilodimou, H. D., & Gamvroula, D. E. (2021). Spatial Distribution and Evaluation of Arsenic and Zinc Content in the Soil of a Karst Landscape. *Sustainability*, *13*(12).

Allen, D. E., Singh, B. P., & Dalal, R. C. (2011). Soil Health Indicators Under Climate Change: A Review of Current Knowledge. In B. P. Singh, A. L. Cowie, & K. Y. Chan (Eds.), *Soil Health and Climate Change* (pp. 25-45). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-20256-8_2

Almendra-Martín, L., Martínez-Fernández, J., Piles, M., González-Zamora, Á., Benito-Verdugo, P., & Gaona, J. (2022). Analysis of soil moisture trends in Europe using rank-based and empirical decomposition approaches. *Global and Planetary Change*, *215*, 103868. https://doi.org/https://doi.org/10.1016/j.gloplacha.2022.103868

Andrea, P., Carla, L., & Monti, A. (2018). Areas with Natural Constraints to Agriculture: Possibilities and Limitations for The Cultivation of Switchgrass (Panicum Virgatum L.) and Giant Reed (Arundo Donax L.) in Europe

In *Land Allocation for Biomass Crops*. https://doi.org/doi:10.1007/978-3-319-74536-7_3

Anestis, V., Bartzanas, T., & Kittas, C. (2015). Life cycle inventory analysis for the milk produced in a Greek commercial dairy farm - The link to Precision Livestock Farming. Precision Livestock Farming 2015 - Papers Presented at the 7th European Conference on Precision Livestock Farming, ECPLF 2015,

Antón, R., Arricibita, F. J., Ruiz-Sagaseta, A., Enrique, A., de Soto, I., Orcaray, L., Zaragüeta, A., & Virto, I. (2021). Soil organic carbon monitoring to assess agricultural climate change adaptation practices in Navarre, Spain [Article]. *Regional Environmental Change*, *21*(3), Article 63. https://doi.org/10.1007/s10113-021-01788-w

Archidona-Yuste, A., Wiegand, T., Eisenhauer, N., Cantalapiedra-Navarrete, C., Palomares-Rius, J. E., & Castillo, P. (2021). Agriculture causes homogenization of plant-feeding nematode communities at the regional scale [Article]. *Journal of Applied Ecology*, *58*(12), 2881-2891. https://doi.org/10.1111/1365-2664.14025

Arenas-Montaño, V., Fenton, O., Moore, B., & Healy, M. G. (2021). Evaluation of the fertiliser replacement value of phosphorus-saturated filter media [Review]. *Journal of Cleaner Production*, *291*, Article 125943. https://doi.org/10.1016/j.jclepro.2021.125943

Arias, M. E., González-Pérez, J. A., González-Vila, F. J., & Ball, A. S. (2005). Soil health—a new challenge for microbiologists and chemists. *International Microbiology*, *8*, 13-21.

Assennato, F., Di Leginio, M., D'Antona, M., Marinosci, I., Congedo, L., Riitano, N., Luise, A., & Munafò, M. (2020). Land degradation assessment for sustainable soil management. *Italian Journal of Agronomy*, *15*(4), 299-305. https://doi.org/10.4081/ija.2020.1770

Aust, G., Heinrich, F., Horvath, D., Musil, A., Foldal, C., & Jandl, R. (2020). Conversion of agricultural soils in Austria—A case study for a community in Upper Austria [Article]. *Bodenkultur*, *71*(2), 69-76. https://doi.org/10.2478/boku-2020-0007

Baartman, J. E. M., Nunes, J. P., van Delden, H., Vanhout, R., & Fleskens, L. (2022). The Effects of Soil Improving Cropping Systems (SICS) on Soil Erosion and Soil Organic Carbon Stocks across Europe: A Simulation Study [Article]. *Land*, *11*(6), Article 943. https://doi.org/10.3390/land11060943

Bach, E. M., Ramirez, K. S., Fraser, T. D., & Wall, D. H. (2020). Soil biodiversity integrates solutions for a sustainable future [Review]. *Sustainability (Switzerland)*, *12*(7), Article 2662. https://doi.org/10.3390/su12072662

Bačová Mitková, V. (2020). Effect of the data lenght and seasonality on the accuracy of T-year discharges estimation: Case study on the Topľa River. *Acta Hydrologica Slovaca*, *20*(2). https://doi.org/10.31577/ahs-2019-0020.02.0013

Bahr, A., Ellström, M., Schnoor, T. K., Påhlsson, L., & Olsson, P. A. (2012). Long-term changes in vegetation and soil chemistry in a calcareous and sandy semi-natural grassland. *Flora - Morphology, Distribution, Functional Ecology of Plants*, *207*(5), 379-387. https://doi.org/https://doi.org/10.1016/j.flora.2012.03.003

Bais-Moleman, A. L., Schulp, C. J. E., & Verburg, P. H. (2019). Assessing the environmental impacts of production- and consumption-side measures in sustainable agriculture intensification in the European Union [Article]. *Geoderma*, *338*, 555-567. https://doi.org/10.1016/j.geoderma.2018.11.042

Bamière, L., Bellassen, V., Angers, D., Cardinael, R., Ceschia, E., Chenu, C., Constantin, J., Delame, N., Diallo, A., Graux, A. I., Houot, S., Klumpp, K., Launay, C., Letort, E., Martin, R., Mézière, D., Mosnier, C., Réchauchère, O., Schiavo, M., . . . Pellerin, S. (2023). A marginal abatement cost curve for climate change mitigation by additional carbon storage in French agricultural land [Article]. *Journal of Cleaner Production*, *383*, Article 135423. https://doi.org/10.1016/j.jclepro.2022.135423

Banwart, S., Bernasconi, S. M., Bloem, J., Blum, W., Brandao, M., Brantley, S., Chabaux, F., Duffy, C., Kram, P., Lair, G., Lundin, L., Nikolaidis, N., Novak, M., Panagos, P., Ragnarsdottir, K. V., Reynolds, B., Rousseva, S., de Ruiter, P., van Gaans, P., . . . Zhang, B. (2011). Soil processes and func tions in critical zone observatories: Hypotheses and experimental design [Article]. *Vadose Zone Journal*, *10*(3), 974-987. https://doi.org/10.2136/vzj2010.0136

Barberá, G. G., Martínez-Garagarza, X., Martínez-Mena, M., & Castillo, V. M. (2019). Soil moisture dynamics alone does not explain differences in growth associated to organic amendment in a reforestation of a semiarid ecosystem. *Catena*, *180*, 383-391. https://doi.org/10.1016/j.catena.2019.05.006

Barbero-Sierra, C., Marques, M. J., & Ruíz-Pérez, M. (2013). The case of urban sprawl in Spain as an active and irreversible driving force for desertification [Article]. *Journal of Arid Environments*, *90*, 95-102. https://doi.org/10.1016/j.jaridenv.2012.10.014

Barbero-Sierra, C., Marques, M. J., Ruiz-Pérez, M., Escadafal, R., & Exbrayat, W. (2015). How is Desertification Research Addressed in Spain? Land Versus Soil Approaches. *Land Degradation & Development*, *26*(5), 423-432. https://doi.org/https://doi.org/10.1002/ldr.2344

Barbosa, B., Costa, J., & Fernando, A. L. (2018). Production of energy crops in heavy metals contaminated land: Opportunities and risks. In *Land Allocation for Biomass Crops: Challenges and Opportunities with Changing Land Use* (pp. 83-102). https://doi.org/10.1007/978-3-319-74536-7_5

Batjes, N. H. (2014). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, *65*(1), 10-21. https://doi.org/https://doi.org/10.1111/ejss.12114_2

Baumgarten, A., Haslmayr, H. P., Schwarz, M., Huber, S., Weiss, P., Obersteiner, E., Aust, G., Englisch, M., Horvath, D., Leitgeb, E., Foldal, C., Rodlauer, C., Bohner, A., Spiegel, H., & Jandl, R. (2021). Organic soil carbon in Austria – Status quo and foreseeable trends [Article]. *Geoderma*, *402*, Article 115214. https://doi.org/10.1016/j.geoderma.2021.115214

Bazzoffi, P., & Gardin, L. (2011). Effectiveness of the GAEC standard of cross compliance retain terraces on soil erosion control [Article]. *Italian Journal of Agronomy*, *6*(SUPL.1), 43-51. https://doi.org/10.4081/ija.2011.6.s1.e6

Bedoussac, L., Journet, E. P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., Prieur, L., & Justes, E. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review [Review]. *Agronomy for Sustainable Development*, *35*(3), 911-935. https://doi.org/10.1007/s13593-014-0277-7

Ben Hamed, K., Castagna, A., Ranieri, A., García-Caparrós, P., Santin, M., Hernandez, J. A., & Espin, G. B. (2021). Halophyte based Mediterranean agriculture in the contexts of food insecurity and global climate change [Article]. *Environmental and Experimental Botany*, *191*, Article 104601. https://doi.org/10.1016/j.envexpbot.2021.104601

Berhe, A. A. (2019). Chapter 3 - Drivers of soil change. In M. Busse, C. P. Giardina, D. M. Morris, & D. S. Page-Dumroese (Eds.), *Developments in Soil Science* (Vol. 36, pp. 27-42). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-444-63998-1.00003-3

Berteni, F., & Grossi, G. (2020). Water Soil Erosion Evaluation in a Small Alpine Catchment Located in Northern Italy: Potential Effects of Climate Change. *Geosciences*, *10*(10).

Beyer, C., Liebersbach, H., & Höper, H. (2015). Multiyear greenhouse gas flux measurements on a temperate fen soil used for cropland or grassland [Article]. *Journal of Plant Nutrition and Soil Science*, *178*(1), 99-111. https://doi.org/10.1002/jpln.201300396

Bianchi, A., Larmola, T., Kekkonen, H., Saarnio, S., & Lång, K. (2021). Review of Greenhouse Gas Emissions from Rewetted Agricultural Soils [Review]. *Wetlands*, *41*(8), Article 108. https://doi.org/10.1007/s13157-021-01507-5

Bielińska, E. J., Futa, B., Ukalska-Jaruga, A., Weber, J., Chmielewski, S., Wesołowska, S., Mocek-Płóciniak, A., Patkowski, K., & Mielnik, L. (2018). Mutual relations between PAHs derived from atmospheric deposition, enzymatic activity, and humic substances in soils of differently urbanized areas. *Journal of Soils and Sediments*, *18*(8), 2682-2691. https://doi.org/10.1007/s11368-018-1937-z

Bilas, G., Karapetsas, N., Gobin, A., Mesdanitis, K., Toth, G., Hermann, T., Wang, Y., Luo, L., Koutsos, T. M., Moshou, D., & Alexandridis, T. K. (2022). Land Suitability Analysis as a Tool for Evaluating Soil-Improving Cropping Systems [Article]. *Land*, *11*(12), Article 2200. https://doi.org/10.3390/land11122200

Bisaro, A., Kirk, M., Zdruli, P., & Zimmermann, W. (2014). Global drivers setting desertification research priorities: Insights from a stakeholder consultation forum [Article]. *Land Degradation and Development*, *25*(1), 5-16. https://doi.org/10.1002/ldr.2220

Blasi, S., Menta, C., Balducci, L., Conti, F. D., Petrini, E., & Piovesan, G. (2013). Soil microarthropod communities from Mediterranean forest ecosystems in Central Italy under different disturbances. *Environ Monit Assess*, *185*(2), 1637-1655. https://doi.org/10.1007/s10661-012-2657-2

Blum, W. E. H. (2013). Soil and Land Resources for Agricultural Production: General Trends and Future Scenarios-A Worldwide Perspective [Article]. *International Soil and Water Conservation Research*, *1*(3), 1-14. https://doi.org/10.1016/S2095-6339(15)30026-5

Bobuľská, L., Demková, L., Čerevková, A., & Renčo, M. (2019). Impact of Peatland Restoration on Soil Microbial Activity and Nematode Communities. *Wetlands*, *40*(4), 865-875. https://doi.org/10.1007/s13157-019-01214-2

Boeddinghaus, R. S., Marhan, S., Berner, D., Boch, S., Fischer, M., Hölzel, N., Kattge, J., Klaus, V. H., Kleinebecker, T., Oelmann, Y., Prati, D., Schäfer, D., Schöning, I., Schrumpf, M., Sorkau, E., Kandeler, E., & Manning, P. (2019). Plant functional trait shifts explain concurrent changes in the structure and function of grassland soil microbial communities. *Journal of Ecology*, *107*(5), 2197-2210. https://doi.org/https://doi.org/10.1111/1365-2745.13182

Boeddinghaus, R. S., Nunan, N., Berner, D., Marhan, S., & Kandeler, E. (2015). Do general spatial relationships for microbial biomass and soil enzyme activities exist in temperate grassland soils? *Soil Biology and Biochemistry*, *88*, 430-440. https://doi.org/https://doi.org/10.1016/j.soilbio.2015.05.026

Bommarez, T., Cools, N., & De Vos, B. (2021). *Heavy metals in forest floors and topsoils of ICP Forests Level I plots Based on the combined Forest Soil Condition Database – Level I (FSCDB.LI)* (Report of the Research Institute for Nature and Forest 2021 (5), Issue. https://www.sciencedirect.com/science/article/pii/S0048969721008822

Bonin, C., & Lal, R. (2012). Bioethanol Potentials and Life-Cycle Assessments of Biofuel Feedstocks [Article]. *Critical Reviews in Plant Sciences*, *31*(4), 271-289. https://doi.org/10.1080/07352689.2011.645438

Bordoni, M., Cislaghi, A., Vercesi, A., Bischetti, G. B., & Meisina, C. (2020). Effects of plant roots on soil shear strength and shallow landslide proneness in an area of northern Italian Apennines. *Bulletin of Engineering Geology and the Environment*, *79*(7), 3361-3381. https://doi.org/10.1007/s10064-020-01783-1

Bordoni, M., Vivaldi, V., Ciabatta, L., Brocca, L., & Meisina, C. (2023). Temporal prediction of shallow landslides exploiting soil saturation degree derived by ERA5-Land products. *Bulletin of Engineering Geology and the Environment*, *82*(8), 308. https://doi.org/10.1007/s10064-023-03304-2

Borrelli, P., Panagos, P., Alewell, C., Ballabio, C., de Oliveira Fagundes, H., Haregeweyn, N., Lugato, E., Maerker, M., Poesen, J., Vanmaercke, M., & Robinson, D. A. (2023). Policy implications of multiple concurrent soil erosion processes in European farmland [Article]. *Nature Sustainability*, *6*(1), 103-112. https://doi.org/10.1038/s41893-022-00988-4

Borrelli, P., Paustian, K., Panagos, P., Jones, A., Schütt, B., & Lugato, E. (2016). Effect of Good Agricultural and Environmental Conditions on erosion and soil organic carbon balance: A national case study [Article]. *Land Use Policy*, *50*, 408-421. https://doi.org/10.1016/j.landusepol.2015.09.033

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. V., Montanarella, L., & Panagos, P. (2017). An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, *8*(1), 2013. https://doi.org/10.1038/s41467-017-02142-7

Bottero, M., Bravi, M., Caprioli, C., & Dell'Anna, F. (2023). Combining Revealed and Stated Preferences to design a new urban park in a metropolitan area of North-Western Italy. *Ecological Modelling*, *483*, 110436. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2023.110436

Bouzouidja, R., Béchet, B., Hanzlikova, J., Sněhota, M., Le Guern, C., Capiaux, H., Jean-Soro, L., Claverie, R., Joimel, S., Schwartz, C., Guénon, R., Szkordilisz, F., Körmöndi, B., Musy, M., Cannavo, P., & Lebeau, T. (2021). Simplified performance assessment methodology for addressing soil quality of nature-based solutions. *Journal of Soils and Sediments*, *21*(5), 1909-1927. https://doi.org/10.1007/s11368-020-02731-y

Braguglia, C. M., Coors, A., Gallipoli, A., Gianico, A., Guillon, E., Kunkel, U., Mascolo, G., Richter, E., Ternes, T. A., Tomei, M. C., & Mininni, G. (2015). Quality assessment of digested sludges produced by advanced stabilization processes [Article]. *Environmental Science and Pollution Research*, *22*(10), 7216-7235. https://doi.org/10.1007/s11356-014-3090-6

Brangarí, A. C., Lyonnard, B., & Rousk, J. (2022). Soil depth and tillage can characterize the soil microbial responses to drying-rewetting. *Soil Biology and Biochemistry*, *173*, 108806. https://doi.org/https://doi.org/10.1016/j.soilbio.2022.108806

Braun, D., de Jong, R., Schaepman, M. E., Furrer, R., Hein, L., Kienast, F., & Damm, A. (2019). Ecosystem service change caused by climatological and non-climatological drivers: a Swiss case study. *Ecological Applications*, *29*(4), e01901. https://doi.org/https://doi.org/10.1002/eap.1901

Brevik, E. C. (2013). The Potential Impact of Climate Change on Soil Properties and Processes and Corresponding Influence on Food Security. *Agriculture*, *3*(3), 398-417.

Brevik, E. C., Calzolari, C., Miller, B. A., Pereira, P., Kabala, C., Baumgarten, A., & Jordán, A. (2016). Soil mapping, classification, and pedologic modeling: History and future directions [Article]. *Geoderma*, *264*, 256-274. https://doi.org/10.1016/j.geoderma.2015.05.017

Bruno, D., Sorando, R., Álvarez-Farizo, B., Castellano, C., Céspedes, V., Gallardo, B., Jiménez, J. J., López, M. V., López-Flores, R., Moret-Fernández, D., Navarro, E., Picazo, F., Sevilla-Callejo, M., Tormo, J., Vidal-Macua, J. J., Nicolau, J. M., & Comín, F. A. (2021). Depopulation impacts on ecosystem services in Mediterranean rural areas [Article]. *Ecosystem Services*, *52*, Article 101369. https://doi.org/10.1016/j.ecoser.2021.101369

Bullock, P. (2005). CLIMATE CHANGE IMPACTS. In D. Hillel (Ed.), *Encyclopedia of Soils in the Environment* (pp. 254-262). Elsevier. https://doi.org/https://doi.org/10.1016/B0-12-348530-4/00089-8

Bunzel, K., Kattwinkel, M., Schauf, M., & Thrän, D. (2014). Energy crops and pesticide contamination: Lessons learnt from the development of energy crop cultivation in Germany [Article]. *Biomass and Bioenergy*, *70*, 416-428. https://doi.org/10.1016/j.biombioe.2014.08.016

Burszta-Adamiak, E., Biniak-Pieróg, M., Dąbek, P. B., & Sternik, A. (2023). Rain garden hydrological performance – Responses to real rainfall events. *Science of The Total*

Environment, *887*, 164153. https://doi.org/https://doi.org/10.1016/j.scitotenv.2023.164153

Buschmann, C., Röder, N., Berglund, K., Berglund, Ö., Lærke, P. E., Maddison, M., Mander, Ü., Myllys, M., Osterburg, B., & van den Akker, J. J. H. (2020). Perspectives on agriculturally used drained peat soils: Comparison of the socioeconomic and ecological business environments of six European regions [Article]. *Land Use Policy*, *90*, Article 104181. https://doi.org/10.1016/j.landusepol.2019.104181

Cabini, E., Fontana, L., Malavasi, P., & Iavicoli, I. (2018). Land use: The perception of risk by the citizens and local administrators in the North of Italy [Article]. *Land Use Policy*, *76*, 553-564. https://doi.org/10.1016/j.landusepol.2018.02.036

Cachada, A., Pato, P., Rocha-Santos, T., da Silva, E. F., & Duarte, A. C. (2012). Levels, sources and potential human health risks of organic pollutants in urban soils. *Science of The Total Environment*, *430*, 184-192. https://doi.org/https://doi.org/10.1016/j.scitotenv.2012.04.075

Cagnarini, C., Blyth, E., Emmett, B. A., Evans, C. D., Griffiths, R. I., Keith, A., Jones, L., Lebron, I., McNamara, N. P., Puissant, J., Reinsch, S., Robinson, D. A., Rowe, E. C., Thomas, A. R. C., Smart, S. M., Whitaker, J., & Cosby, B. J. (2019). Zones of influence for soil organic matter dynamics: A conceptual framework for data and models. *Global Change Biology*, *25*(12), 3996-4007. https://doi.org/https://doi.org/10.1111/gcb.14787

Calzolari, C., Tarocco, P., Lombardo, N., Marchi, N., & Ungaro, F. (2020). Assessing soil ecosystem services in urban and peri-urban areas: From urban soils survey to providing support tool for urban planning. *Land Use Policy*, *99*, 105037. https://doi.org/https://doi.org/10.1016/j.landusepol.2020.105037

Camacho, I., Góis, A., Camacho, R., Nóbrega, V., & Fernandez. (2018). The impact of urban and forest fires on the airborne fungal spore aerobiology. *Aerobiologia*, *34*(4), 585-592. https://doi.org/10.1007/s10453-018-9530-x

Cameira, M. R., Rolim, J., Valente, F., Faro, A., Dragosits, U., & Cordovil, C. M. D. S. (2019). Spatial distribution and uncertainties of nitrogen budgets for agriculture in the Tagus river basin in Portugal – Implications for effectiveness of mitigation measures [Article]. *Land Use Policy*, *84*, 278-293. https://doi.org/10.1016/j.landusepol.2019.02.028

Cantón, Y., Solé-Benet, A., de Vente, J., Boix-Fayos, C., Calvo-Cases, A., Asensio, C., & Puigdefábregas, J. (2011). A review of runoff generation and soil erosion across scales in semiarid south-eastern Spain. *Journal of Arid Environments*, *75*(12), 1254-1261. https://doi.org/https://doi.org/10.1016/j.jaridenv.2011.03.004

Cardoso, E. J. B. N., Vasconcellos, R. L. F., Bini, D., Miyauchi, M. Y. H., Santos, C. A. d., Alves, P. R. L., Paula, A. M. d., Nakatani, A. S., Pereira, J. d. M., & Nogueira, M. A. (2013). Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? *Scientia Agricola*, *70*. https://doi.org/https://doi.org/10.1590/S0103-90162013000400009

Carrer, D., Pique, G., Ferlicoq, M., Ceamanos, X., & Ceschia, E. (2018). What is the potential of cropland albedo management in the fight against global warming? A case study based on the use of cover crops [Article]. *Environmental Research Letters*, *13*(4), Article 044030. https://doi.org/10.1088/1748-9326/aab650

Carrero, J. A., Arrizabalaga, I., Bustamante, J., Goienaga, N., Arana, G., & Madariaga, J. M. (2013). Diagnosing the traffic impact on roadside soils through a multianalytical data analysis of the concentration profiles of traffic-related elements. *Science of The Total Environment*, *458-460*, 427-434. https://doi.org/https://doi.org/10.1016/j.scitotenv.2013.04.047

Carvalho-Santos, C., Marcos, B., Nunes, J. P., Regos, A., Palazzi, E., Terzago, S., Monteiro, A. T., & Honrado, J. P. (2019). Hydrological Impacts of Large Fires and Future Climate: Modeling Approach Supported by Satellite Data. *Remote Sensing*, *11*(23).

Carvalho, F., Treasure, L., Robinson, S. J. B., Blaydes, H., Exley, G., Hayes, R., Howell, B., Keith, A., Montag, H., Parker, G., Sharp, S. P., Witten, C., & Armstrong, A. (2023). Towards a standardized protocol to assess natural capital and ecosystem services in solar parks. *Ecological Solutions and Evidence*, *4*(1), e12210. https://doi.org/https://doi.org/10.1002/2688-8319.12210

Case, S. D. C., Oelofse, M., Hou, Y., Oenema, O., & Jensen, L. S. (2017). Farmer perceptions and use of organic waste products as fertilisers – A survey study of potential benefits and barriers [Article]. *Agricultural Systems*, *151*, 84-95. https://doi.org/10.1016/j.agsy.2016.11.012

Catania, V., Bueno, R. S., Alduina, R., Grilli, E., La Mantia, T., Castaldi, S., & Quatrini, P. (2022). Soil microbial biomass and bacterial diversity in southern European regions vulnerable to desertification. *Ecological Indicators*, *145*, 109725. https://doi.org/https://doi.org/10.1016/j.ecolind.2022.109725

Catorci, A., & Gatti, R. (2010). Floristic composition and spatial distribution assessment of montane mesophilous grasslands in the central Apennines, Italy: A multi-scale and diachronic approach. *Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology*, *144*(4), 793-804. https://doi.org/10.1080/11263504.2010.513864

Cerdà, A., Ackermann, O., Terol, E., & Rodrigo-Comino, J. (2019). Impact of farmland abandonment on water resources and soil conservation in citrus plantations in eastern Spain [Article]. *Water (Switzerland)*, *11*(4), Article 824. https://doi.org/10.3390/w11040824

Cesco, S., Sambo, P., Borin, M., Basso, B., Orzes, G., & Mazzetto, F. (2023). Smart agriculture and digital twins: Applications and challenges in a vision of sustainability [Article]. *European Journal of Agronomy*, *146*, Article 126809. https://doi.org/10.1016/j.eja.2023.126809

Chakir, R., & Le Gallo, J. (2013). Predicting land use allocation in France: A spatial panel data analysis. *Ecological Economics*, *92*, 114-125. https://doi.org/10.1016/j.ecolecon.2012.04.009

Ciriminna, D., Ferreri, G. B., Noto, L. V., & Celauro, C. (2022). Numerical Comparison of the Hydrological Response of Different Permeable Pavements in Urban Area. *Sustainability*, *14*(9).

Clark, J. M., Bottrell, S. H., Evans, C. D., Monteith, D. T., Bartlett, R., Rose, R., Newton, R. J., & Chapman, P. J. (2010). The importance of the relationship between scale and process in understanding long-term DOC dynamics. *Sci Total Environ*, *408*(13), 2768-2775. https://doi.org/10.1016/j.scitotenv.2010.02.046

COM(2019) 640 final, (2019). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640&qid=1705579347456

COM(2021) 400 final, (2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827

COM(2021) 699 final, EU (2021).

COM(2022) 304 final, 2022/0195 (2022).

COM(2023) 416 final, 2023/0232 (2023).

Costa, D., Freitas, H., & Sousa, J. P. (2013). Influence of seasons and land-use practices on soil microbial activity and metabolic diversity in the “Montado ecosystem”. *European Journal of Soil Biology*, *59*, 22-30. https://doi.org/https://doi.org/10.1016/j.ejsobi.2013.08.003

Cybulak, M., Sokołowska, Z., & Boguta, P. (2019). Impact of Biochar on Physicochemical Properties of Haplic Luvisol Soil under Different Land Use: A Plot Experiment. *Agronomy*, *9*(9).

D'Acqui, L. P., Santi, C. A., Vizza, F., & Certini, G. (2015). Living and dead soil organic matter under different land uses on a Mediterranean island. *European Journal of Soil Science*, *66*(2), 298-310. https://doi.org/10.1111/ejss.12219

D'Odorico, P., Bhattachan, A., Davis, K. F., Ravi, S., & Runyan, C. W. (2013). Global desertification: Drivers and feedbacks [Article]. *Advances in Water Resources*, *51*, 326-344. https://doi.org/10.1016/j.advwatres.2012.01.013

d'Annunzio, R., Sandker, M., Finegold, Y., & Min, Z. (2015). Projecting global forest area towards 2030. *Forest Ecology and Management*, *352*, 124-133. https://doi.org/10.1016/j.foreco.2015.03.014

Dadashpoor, H., & Ahani, S. (2021). Explaining objective forces, driving forces, and causal mechanisms affecting the formation and expansion of the peri-urban areas: A critical realism approach. *Land Use Policy*, *102*, 105232. https://doi.org/https://doi.org/10.1016/j.landusepol.2020.105232

Dajić, A., Mihajlović, M., Jovanović, M., Karanac, M., Stevanović, D., & Jovanović, J. (2016). Landfill design: need for improvement of water and soil protection requirements in EU Landfill Directive. *Clean Technologies and Environmental Policy*, *18*(3), 753-764. https://doi.org/10.1007/s10098-015-1046-2

Dal Ferro, N., Quinn, C., & Morari, F. (2018). A Bayesian belief network framework to predict SOC dynamics of alternative management scenarios [Article]. *Soil and Tillage Research*, *179*, 114-124. https://doi.org/10.1016/j.still.2018.01.002

Dangal, S. R. S., Schwalm, C., Cavigelli, M. A., Gollany, H. T., Jin, V. L., & Sanderman, J. (2022). Improving Soil Carbon Estimates by Linking Conceptual Pools Against Measurable Carbon Fractions in the DAYCENT Model Version 4.5 [Article]. *Journal of Advances in Modeling Earth Systems*, *14*(5), Article e2021MS002622. https://doi.org/10.1029/2021MS002622

David, T. S., Pinto, C. A., Nadezhdina, N., & David, J. S. (2016). Water and forests in the Mediterranean hot climate zone: a review based on a hydraulic interpretation of tree functioning. *Forest Systems*, *25*(2). https://doi.org/10.5424/fs/2016252-08899

De Laurentiis, V., Secchi, M., Bos, U., Horn, R., Laurent, A., & Sala, S. (2019). Soil quality index: Exploring options for a comprehensive assessment of land use impacts in LCA. *Journal of Cleaner Production*, *215*, 63-74. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.12.238

De Schrijver, A., De Frenne, P., Staelens, J., Verstraeten, G., Muys, B., Vesterdal, L., Wuyts, K., van Nevel, L., Schelfhout, S., De Neve, S., & Verheyen, K. (2012). Tree species traits cause divergence in soil acidification during four decades of postagricultural forest development [Article]. *Global Change Biology*, *18*(3), 1127-1140. https://doi.org/10.1111/j.1365-2486.2011.02572.x

Debolini, M., Schoorl, J. M., Temme, A., Galli, M., & Bonari, E. (2015). Changes in Agricultural Land Use Affecting Future Soil Redistribution Patterns: A Case Study in Southern Tuscany (Italy) [Article]. *Land Degradation and Development*, *26*(6), 574-586. https://doi.org/10.1002/ldr.2217

Deelstra, J., Øygarden, L., Blankenberg, A. G. B., & Eggestad, H. O. (2011). Climate change and runoff from agricultural catchments in Norway [Article]. *International Journal of Climate Change Strategies and Management*, *3*(4), 345-360. https://doi.org/10.1108/17568691111175641

Degnet, M. B., Hansson, H., Hoogstra-Klein, M. A., & Roos, A. (2022). The role of personal values and personality traits in environmental concern of non-industrial private forest owners in Sweden. *Forest Policy and Economics*, *141*. https://doi.org/10.1016/j.forpol.2022.102767

Delgado-Artés, R., Garófano-Gómez, V., Oliver-Villanueva, J. V., & Rojas-Briales, E. (2022). Land use/cover change analysis in the Mediterranean region: a regional case study of forest evolution in Castelló (Spain) over 50 years [Article]. *Land Use Policy*, *114*, Article 105967. https://doi.org/10.1016/j.landusepol.2021.105967

Delibas, M., Tezer, A., & Kuzniecow Bacchin, T. (2021). Towards embedding soil ecosystem services in spatial planning. *Cities*, *113*, 103150. https://doi.org/https://doi.org/10.1016/j.cities.2021.103150

Dias, A. T. C., Krab, E. J., Mariën, J., Zimmer, M., Cornelissen, J. H. C., Ellers, J., Wardle, D. A., & Berg, M. P. (2013). Traits underpinning desiccation resistance explain distribution patterns of terrestrial isopods. *Oecologia*, *172*(3), 667-677. https://doi.org/10.1007/s00442-012-2541-3

Díaz de Otálora, X., Epelde, L., Arranz, J., Garbisu, C., Ruiz, R., & Mandaluniz, N. (2021). Regenerative rotational grazing management of dairy sheep increases springtime grass production and topsoil carbon storage [Article]. *Ecological Indicators*, *125*, Article 107484. https://doi.org/10.1016/j.ecolind.2021.107484

Dietze, V., & Feindt, P. H. (2023). Innovation systems for controlled-environment food production in urban contexts: a dynamic case study analysis of combined plant, fish and insect production in Berlin. *International Journal of Agricultural Sustainability*, *21*(1), 2166230. https://doi.org/10.1080/14735903.2023.2166230

Drahota, P., Raus, K., Rychlíková, E., & Rohovec, J. (2018). Bioaccessibility of As, Cu, Pb, and Zn in mine waste, urban soil, and road dust in the historical mining village of Kaňk, Czech Republic. *Environmental Geochemistry and Health*, *40*(4), 1495-1512. https://doi.org/10.1007/s10653-017-9999-1

Drewer, J., Dufossé, K., Skiba, U. M., & Gabrielle, B. (2016). Changes in isotopic signatures of soil carbon and CO2 respiration immediately and one year after Miscanthus removal [Article]. *GCB Bioenergy*, *8*(1), 59-65. https://doi.org/10.1111/gcbb.12230

Du, X., Jian, J., Du, C., & Stewart, R. D. (2022). Conservation management decreases surface runoff and soil erosion. *International Soil and Water Conservation Research*, *10*(2), 188-196. https://doi.org/https://doi.org/10.1016/j.iswcr.2021.08.001

Dufossé, K., Drewer, J., Gabrielle, B., & Drouet, J. L. (2014). Effects of a 20-year old Miscanthus × giganteus stand and its removal on soil characteristics and greenhouse gas emissions [Article]. *Biomass and Bioenergy*, *69*, 198-210. https://doi.org/10.1016/j.biombioe.2014.07.003

Dumont, B., Ryschawy, J., Duru, M., Benoit, M., Chatellier, V., Delaby, L., Donnars, C., Dupraz, P., Lemauviel-Lavenant, S., Méda, B., Vollet, D., & Sabatier, R. (2019). Review: Associations among goods, impacts and ecosystem services provided by livestock farming [Review]. *Animal*, *13*(8), 1773-1784. https://doi.org/10.1017/S1751731118002586

Ebenhard, T., Forsberg, M., Lind, T., Nilsson, D., Andersson, R., Emanuelsson, U., Eriksson, L., Hultåker, O., Iwarsson Wide, M., & Ståhl, G. (2017). Environmental effects of brushwood harvesting for bioenergy. *Forest Ecology and Management*, *383*, 85-98. https://doi.org/10.1016/j.foreco.2016.05.022

EC. (2012). *Guidelines on best practice to limit, mitigate or compensate soil sealing*.

EC. (2021). *European Missions: A Soil Deal for Europe: 100 living labs and lighthouses to lead the transition towards healthy soils by 2030 – Implementation plan.*

EC. (2023a). *COMMISSION STAFF WORKING DOCUMENT Drivers of food security*.

EC. (2023b). *Horizon Europe Work Programme 2023-2024*.

EC. (2023c). *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*

identifying Member States at risk of not meeting the 2025 preparing for re-use and *recycling target for municipal waste, the 2025 recycling target for packaging waste and the 2035 municipal waste landfilling reduction target*.

EEA. (1999). *Environmental indicators:Typology and overview* (Technical report No 25/1999, Issue. https://www.eea.europa.eu/publications/TEC25

EEA. (2022a). *Progress in the management of contaminated sites in the EU*. European environmental Agency (EEA). Retrieved 19 January from https://www.eea.europa.eu/en/analysis/indicators/progress-in-the-management-of?utm_source=EEASubscriptions&utm_medium=RSSFeeds&utm_campaign=Generic&activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366

EEA. (2022b). *Soil monitoring in Europe — Indicators and thresholds for soil health assessments* (EEA report, Issue.

EEA. (2023, 23.3.2023). *Net land take in cities and commuting zones in Europe*. European Environment Agency. Retrieved 22.01 from https://www.eea.europa.eu/en/analysis/indicators/net-land-take-in-cities

EEA. (2024). *EEA Glossary*. European Environment Agency (EEA). https://www.eea.europa.eu/help/glossary/eea-glossary

Efthimiou, N., Psomiadis, E., Papanikolaou, I., Soulis, K. X., Borrelli, P., & Panagos, P. (2022). A new high resolution object-oriented approach to define the spatiotemporal dynamics of the cover-management factor in soil erosion modelling [Article]. *Catena*, *213*, Article 106149. https://doi.org/10.1016/j.catena.2022.106149

Egidi, G., Cividino, S., Paris, E., Palma, A., Salvati, L., & Cudlin, P. (2021). Assessing the impact of multiple drivers of land sensitivity to desertification in a Mediterranean country. *Environmental Impact Assessment Review*, *89*, 106594. https://doi.org/https://doi.org/10.1016/j.eiar.2021.106594

Egidi, G., Zambon, I., Tombolin, I., Salvati, L., Cividino, S., Seifollahi-Aghmiuni, S., & Kalantari, Z. (2020). Unraveling latent aspects of urban expansion: Desertification risk reveals more [Article]. *International Journal of Environmental Research and Public Health*, *17*(11), Article 4001. https://doi.org/10.3390/ijerph17114001

Englmeier, J., Mitesser, O., Benbow, M. E., Hothorn, T., von Hoermann, C., Benjamin, C., Fricke, U., Ganuza, C., Haensel, M., Redlich, S., Riebl, R., Rojas Botero, S., Rummler, T., Steffan-Dewenter, I., Stengel, E., Tobisch, C., Uhler, J., Uphus, L., Zhang, J., & Müller, J. (2022). Diverse Effects of Climate, Land Use, and Insects on Dung and Carrion Decomposition. *Ecosystems*, *26*(2), 397-411. https://doi.org/10.1007/s10021-022-00764-7

Erős, T., Petrovszki, J., & Mórocz, A. (2023). Planning for sustainability: Historical data and remote sensing-based analyses aid landscape design in one of the largest remnant European floodplains. *Landscape and Urban Planning*, *238*, 104837. https://doi.org/https://doi.org/10.1016/j.landurbplan.2023.104837

ESDAC, J.-. (2024). *Glossary*. Retrieved 29.05 from https://esdac.jrc.ec.europa.eu/resource-type/glossary

Estendorfer, J., Stempfhuber, B., Haury, P., Vestergaard, G., Rillig, M. C., Joshi, J., Schroder, P., & Schloter, M. (2017). The Influence of Land Use Intensity on the Plant-Associated Microbiome of Dactylis glomerata L. *Front Plant Sci*, *8*, 930. https://doi.org/10.3389/fpls.2017.00930

Esteves, T. C. J., Kirkby, M. J., Shakesby, R. A., Ferreira, A. J. D., Soares, J. A. A., Irvine, B. J., Ferreira, C. S. S., Coelho, C. O. A., Bento, C. P. M., & Carreiras, M. A. (2012). Mitigating land degradation caused by wildfire: Application of the PESERA model to fire-affected sites in central Portugal. *Geoderma*, *191*, 40-50. https://doi.org/https://doi.org/10.1016/j.geoderma.2012.01.001

EU. (2021). *EU Biodiversity Strategy for 2030 Bringing nature back into our lives*.

Evans, D. L., Quinton, J. N., Davies, J. A. C., Zhao, J., & Govers, G. (2020). Soil lifespans and how they can be extended by land use and management change [Article]. *Environmental Research Letters*, *15*(9), Article 0940b2. https://doi.org/10.1088/1748-9326/aba2fd

Fagúndez, J. (2013). Heathlands confronting global change: drivers of biodiversity loss from past to future scenarios. *Annals of Botany*, *111*(2), 151-172. https://doi.org/10.1093/aob/mcs257

Falcucci, A., Maiorano, L., & Boitani, L. (2007). Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecology*, *22*(4), 617-631. https://doi.org/10.1007/s10980-006-9056-4

FAO. (2023). *Global Soil Partnership*. Retrieved 01 from https://www.fao.org/global-soil-partnership/areas-of-work/awareness-raising/en/?fbclid=IwAR2XiPzSJGLnqE-cqNN_KvJiVx2aRbhTeZWWChgApsUIbNDihef8Z2-oBYY

FAO. (2024). *RECSOIL: Recarbonization of Global Agricultural Soils*. Food and Agriculture Association of The United Nations (FAO) Retrieved 30.05 from https://www.fao.org/global-soil-partnership/areas-of-work/recsoil/what-is-soc/en/

FAO, & UNEP. (2021). *Global Assessment of Soil Pollution*.

Farris, E., Filigheddu, R., Deiana, P., Farris, G. A., & Garau, G. (2010). Short-term effects on sheep pastureland due to grazing abandonment in a Western Mediterranean island ecosystem: A multidisciplinary approach. *Journal for Nature Conservation*, *18*(4), 258-267. https://doi.org/https://doi.org/10.1016/j.jnc.2009.11.003

Feliciano, D., Bouriaud, L., Brahic, E., Deuffic, P., Dobsinska, Z., Jarsky, V., Lawrence, A., Nybakk, E., Quiroga, S., Suarez, C., & Ficko, A. (2017). Understanding private forest owners' conceptualisation of forest management: Evidence from a survey in seven European countries. *Journal of Rural Studies*, *54*, 162-176. https://doi.org/10.1016/j.jrurstud.2017.06.016

Fernández-Guisuraga, J. M., Calvo, L., Ansola, G., Pinto, R., & Sáenz de Miera, L. E. (2022). The effect of sheep grazing abandonment on soil bacterial communities in productive mountain grasslands [Article]. *Science of The Total Environment*, *851*, Article 158398. https://doi.org/10.1016/j.scitotenv.2022.158398

Ferreira, C. S. S., Keizer, J. J., Santos, L. M. B., Serpa, D., Silva, V., Cerqueira, M., Ferreira, A. J. D., & Abrantes, N. (2018). Runoff, sediment and nutrient exports from a Mediterranean vineyard under integrated production: An experiment at plot scale [Article]. *Agriculture, Ecosystems and Environment*, *256*, 184-193. https://doi.org/10.1016/j.agee.2018.01.015

Ferreira, C. S. S., Walsh, R. P. D., & Ferreira, A. J. D. (2018). Degradation in urban areas. *Current Opinion in Environmental Science & Health*, *5*, 19-25. https://doi.org/https://doi.org/10.1016/j.coesh.2018.04.001

Finer, L., Lepisto, A., Karlsson, K., Raike, A., Harkonen, L., Huttunen, M., Joensuu, S., Kortelainen, P., Mattsson, T., Piirainen, S., Sallantaus, T., Sarkkola, S., Tattari, S., & Ukonmaanaho, L. (2021). Drainage for forestry increases N, P and TOC export to boreal surface waters. *Sci Total Environ*, *762*, 144098. https://doi.org/10.1016/j.scitotenv.2020.144098

Fini, A., Frangi, P., Mori, J., Donzelli, D., & Ferrini, F. (2017). Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements. *Environmental Research*, *156*, 443-454. https://doi.org/https://doi.org/10.1016/j.envres.2017.03.032

Florido, M. d. C., Madrid, F., & Madrid, L. (2011). Effect of an organic amendment on availability and bio-accessibility of some metals in soils of urban recreational areas. *Environmental Pollution*, *159*(2), 383-390. https://doi.org/https://doi.org/10.1016/j.envpol.2010.11.002

Földes, G., Kohnová, S., Labat, M. M., & Hlavčová, K. (2020). Predicted Changes in Short-Term Rainfall Intensities and Runoff at the Ipoltica River Basin. *Pollack Periodica*, *15*(3), 172-183. https://doi.org/https://doi.org/10.1556/606.2020.15.3.17

Follmi, D., Baartman, J., Benali, A., & Nunes, J. P. (2022). How do large wildfires impact sediment redistribution over multiple decades? *Earth Surface Processes and Landforms*, *47*(13), 3033-3050. https://doi.org/https://doi.org/10.1002/esp.5441

Forsius, M., Posch, M., Holmberg, M., Vuorenmaa, J., Kleemola, S., Augustaitis, A., Beudert, B., Bochenek, W., Clarke, N., de Wit, H. A., Dirnböck, T., Frey, J., Grandin, U., Hakola, H., Kobler, J., Krám, P., Lindroos, A.-J., Löfgren, S., Pecka, T., . . . Váňa, M. (2021). Assessing critical load exceedances and ecosystem impacts of anthropogenic nitrogen and sulphur deposition at unmanaged forested catchments in Europe. *Science of The Total Environment*, *753*, 141791. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.141791

Fowler, D., Steadman, C. E., Stevenson, D., Coyle, M., Rees, R. M., Skiba, U. M., Sutton, M. A., Cape, J. N., Dore, A. J., Vieno, M., Simpson, D., Zaehle, S., Stocker, B. D., Rinaldi, M., Facchini, M. C., Flechard, C. R., Nemitz, E., Twigg, M., Erisman, J. W., . . . Galloway, J. N. (2015). Effects of global change during the 21st century onthe nitrogen cycle [Review]. *Atmospheric Chemistry and Physics*, *15*(24), 13849-13893. https://doi.org/10.5194/acp-15-13849-2015

Frac, M., Hannula, S. E., Belka, M., & Jedryczka, M. (2018). Fungal Biodiversity and Their Role in Soil Health. *Front Microbiol*, *9*, 707. https://doi.org/10.3389/fmicb.2018.00707

Francos, M., Stefanuto, E. B., Ubeda, X., & Pereira, P. (2019). Long-term impact of prescribed fire on soil chemical properties in a wildland-urban interface. Northeastern Iberian Peninsula. *Sci Total Environ*, *689*, 305-311. https://doi.org/10.1016/j.scitotenv.2019.06.434

Frank, S., Fürst, C., Witt, A., Koschke, L., & Makeschin, F. (2014). Making use of the ecosystem services concept in regional planning—trade-offs from reducing water erosion [Article]. *Landscape Ecology*, *29*(8), 1377-1391. https://doi.org/10.1007/s10980-014-9992-3

Früh-Müller, A., Bach, M., Breuer, L., Hotes, S., Koellner, T., Krippes, C., & Wolters, V. (2019). The use of agri-environmental measures to address environmental pressures in Germany: Spatial mismatches and options for improvement [Article]. *Land Use Policy*, *84*, 347-362. https://doi.org/10.1016/j.landusepol.2018.10.049

Fryer, J., & Williams, I. D. (2021). Regional carbon stock assessment and the potential effects of land cover change. *Science of The Total Environment*, *775*, 145815. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.145815

Fuchslueger, L., Wild, B., Mooshammer, M., Takriti, M., Kienzl, S., Knoltsch, A., Hofhansl, F., Bahn, M., & Richter, A. (2019). Microbial carbon and nitrogen cycling responses to drought and temperature in differently managed mountain grasslands. *Soil Biology and Biochemistry*, *135*, 144-153. https://doi.org/https://doi.org/10.1016/j.soilbio.2019.05.002

García-Ruiz, J. M. (2010). The effects of land uses on soil erosion in Spain: A review [Review]. *Catena*, *81*(1), 1-11. https://doi.org/10.1016/j.catena.2010.01.001

Gatica-Saavedra, P., Aburto, F., Rojas, P., & Echeverría, C. (2022). Soil health indicators for monitoring forest ecological restoration: a critical review. *Restoration Ecology*, *31*(5). https://doi.org/10.1111/rec.13836

Geitner, C., Mayr, A., Rutzinger, M., Löbmann, M. T., Tonin, R., Zerbe, S., Wellstein, C., Markart, G., & Kohl, B. (2021). Shallow erosion on grassland slopes in the European Alps – Geomorphological classification, spatio-temporal analysis, and understanding snow and vegetation impacts. *Geomorphology*, *373*, 107446. https://doi.org/https://doi.org/10.1016/j.geomorph.2020.107446

Gericke, A., Kiesel, J., Deumlich, D., & Venohr, M. (2019). Recent and Future Changes in Rainfall Erosivity and Implications for the Soil Erosion Risk in Brandenburg, NE Germany. *Water*, *11*(5).

Gevaert, A. I., Veldkamp, T. I. E., & Ward, P. J. (2018). The effect of climate type on timescales of drought propagation in an ensemble of global hydrological models. *Hydrology and Earth System Sciences*, *22*(9), 4649-4665. https://doi.org/10.5194/hess-22-4649-2018

Gianico, A., Braguglia, C. M., Gallipoli, A., Montecchio, D., & Mininni, G. (2021). Land application of biosolids in europe: Possibilities, con-straints and future perspectives [Review]. *Water (Switzerland)*, *13*(1), Article 103. https://doi.org/10.3390/w13010103

Gianinetto, M., Aiello, M., Polinelli, F., Frassy, F., Rulli, M. C., Ravazzani, G., Bocchiola, D., Chiarelli, D. D., Soncini, A., & Vezzoli, R. (2019). D-RUSLE: a dynamic model to estimate potential soil erosion with satellite time series in the Italian Alps. *European Journal of Remote Sensing*, *52*(sup4), 34-53. https://doi.org/10.1080/22797254.2019.1669491

Gömann, H., Kreins, P., & Heidecke, C. (2011). How global conditions impact regional agricultural production and nitrogen surpluses in the German Elbe River Basin [Article]. *Regional Environmental Change*, *11*(3), 663-678. https://doi.org/10.1007/s10113-010-0198-1

Gómez-Sagasti, M. T., Hernández, A., Artetxe, U., Garbisu, C., & Becerril, J. M. (2018). How Valuable Are Organic Amendments as Tools for the Phytomanagement of Degraded Soils? The Knowns, Known Unknowns, and Unknowns [Article]. *Frontiers in Sustainable Food Systems*, *2*, Article 68. https://doi.org/10.3389/fsufs.2018.00068

Gómez Giménez, M., de Jong, R., Keller, A., Rihm, B., & Schaepman, M. E. (2019). Studying the Influence of Nitrogen Deposition, Precipitation, Temperature, and Sunshine in Remotely Sensed Gross Primary Production Response in Switzerland. *Remote Sensing*, *11*(9).

Gomiero, T., Pimentel, D., & Paoletti, M. G. (2011). Is There a Need for a More Sustainable Agriculture? [Review]. *Critical Reviews in Plant Sciences*, *30*(1-2), 6-23. https://doi.org/10.1080/07352689.2011.553515

González-Rosado, M., Parras-Alcántara, L., Aguilera-Huertas, J., & Lozano-García, B. (2023). Land conversion impacts on soil macroaggregation, carbon sequestration and preservation in tree orchards located in Mediterranean environment (Spain) [Article]. *Agriculture, Ecosystems and Environment*, *354*, Article 108557. https://doi.org/10.1016/j.agee.2023.108557

Gonzalez, L., & Ortega, F. (2013). IMMIGRATION AND HOUSING BOOMS: EVIDENCE FROM SPAIN*. *Journal of Regional Science*, *53*(1), 37-59. https://doi.org/https://doi.org/10.1111/jors.12010

Gottschalk, P., Smith, J. U., Wattenbach, M., Bellarby, J., Stehfest, E., Arnell, N., Osborn, T. J., Jones, C., & Smith, P. (2012). How will organic carbon stocks in mineral soils evolve under future climate? Global projections using RothC for a range of climate change scenarios. *Biogeosciences*, *9*(8), 3151-3171. https://doi.org/10.5194/bg-9-3151-2012

Greinert, A. (2015). The heterogeneity of urban soils in the light of their properties. *Journal of Soils and Sediments*, *15*(8), 1725-1737. https://doi.org/10.1007/s11368-014-1054-6

Grennfelt, P., Engleryd, A., Forsius, M., Hov, Ø., Rodhe, H., & Cowling, E. (2020). Acid rain and air pollution: 50 years of progress in environmental science and policy. *Ambio*, *49*(4), 849-864. https://doi.org/10.1007/s13280-019-01244-4

Grillakis, M. G., Koutroulis, A. G., Alexakis, D. D., Polykretis, C., & Daliakopoulos, I. N. (2021). Regionalizing Root-Zone Soil Moisture Estimates From ESA CCI Soil Water Index Using Machine Learning and Information on Soil, Vegetation, and Climate [Article]. *Water Resources Research*, *57*(5), Article e2020WR029249. https://doi.org/10.1029/2020WR029249

Gruss, I., Twardowski, J., Nebeská, D., Trögl, J., Stefanovska, T., Pidlisnyuk, V., & Machová, I. (2022). Microarthropods and vegetation as biological indicators of soil quality studied in poor sandy sites at former military facilities. *Land Degradation & Development*, *33*(2), 358-367. https://doi.org/https://doi.org/10.1002/ldr.4157
Haase, D., Kabisch, N., & Haase, A. (2013). Endless Urban Growth? On the Mismatch of Population, Household and Urban Land Area Growth and Its Effects on the Urban Debate. *PLOS ONE*, *8*(6), e66531. https://doi.org/10.1371/journal.pone.0066531
Hájek, M., Horsáková, V., Hájková, P., Coufal, R., Dítě, D., Němec, T., & Horsák, M. (2020). Habitat extremity and conservation management stabilise endangered calcareous fens in a changing world. *Science of The Total Environment*, *719*, 134693. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.134693
Hák, T., Janoušková, S., & Moldan, B. (2016). Sustainable Development Goals: A need for relevant indicators. *Ecological Indicators*, *60*, 565-573. https://doi.org/https://doi.org/10.1016/j.ecolind.2015.08.003
Halecki, W., Kruk, E., & Ryczek, M. (2018). Loss of topsoil and soil erosion by water in agricultural areas: A multi-criteria approach for various land use scenarios in the Western Carpathians using a SWAT model [Article]. *Land Use Policy*, *73*, 363-372. https://doi.org/10.1016/j.landusepol.2018.01.041
Harris, E., Ladreiter-Knauss, T., Butterbach-Bahl, K., Wolf, B., & Bahn, M. (2018). Land-use and abandonment alters methane and nitrous oxide fluxes in mountain grasslands. *Science of The Total Environment*, *628-629*, 997-1008. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.02.119
Haslmayr, H.-P., Geitner, C., Sutor, G., Knoll, A., & Baumgarten, A. (2016). Soil function evaluation in Austria — Development, concepts and examples. *Geoderma*, *264*, 379-387. https://doi.org/https://doi.org/10.1016/j.geoderma.2015.09.023
Hastings, A., Yeluripati, J., Hillier, J., & Smith, P. (2013). Biofuel Crops and Greenhouse Gases. In *Biofuel Crop Sustainability* (pp. 383-405). https://doi.org/10.1002/9781118635797.ch12
Hatten, J., & Liles, G. (2019). A 'healthy' balance – The role of physical and chemical properties in maintaining forest soil function in a changing world. In *Global Change and Forest Soils* (pp. 373-396). https://doi.org/10.1016/b978-0-444-63998-1.00015-x
Haughey, E., Neogi, S., Portugal-Pereira, J., van Diemen, R., & Slade, R. B. (2023). Sustainable intensification and carbon sequestration research in agricultural systems: A systematic review [Review]. *Environmental Science and Policy*, *143*, 14-23. https://doi.org/10.1016/j.envsci.2023.02.018
Häyrinen, L., Mattila, O., Berghäll, S., & Toppinen, A. (2014). Forest Owners' Socio-demographic Characteristics as Predictors of Customer Value: Evidence from Finland. *Small-scale Forestry*, *14*(1), 19-37. https://doi.org/10.1007/s11842-014-9271-9
Head, J. S., Crockatt, M. E., Didarali, Z., Woodward, M.-J., & Emmett, B. A. (2020). The Role of Citizen Science in Meeting SDG Targets around Soil Health. *Sustainability*, *12*(24).
Heikkinen, J., Keskinen, R., Kostensalo, J., & Nuutinen, V. (2022). Climate change induces carbon loss of arable mineral soils in boreal conditions [Article]. *Global Change Biology*, *28*(12), 3960-3973. https://doi.org/10.1111/gcb.16164
Heinze, J., Bergmann, J., Rillig, M. C., & Joshi, J. (2015). Negative biotic soil-effects enhance biodiversity by restricting potentially dominant plant species in grasslands. *Perspectives in Plant Ecology, Evolution and Systematics*, *17*(3), 227-235. https://doi.org/https://doi.org/10.1016/j.ppees.2015.03.002
Helming, K., Daedlow, K., Paul, C., Techen, A. K., Bartke, S., Bartkowski, B., Kaiser, D., Wollschläger, U., & Vogel, H. J. (2018). Managing soil functions for a sustainable bioeconomy—Assessment framework and state of the art. *Land Degradation & Development*, *29*(9), 3112-3126. https://doi.org/10.1002/ldr.3066

Henseler, M., Gallagher, M. B., & Kreins, P. (2022). Microplastic Pollution in Agricultural Soils and Abatement Measures – a Model-Based Assessment for Germany [Article]. *Environmental Modeling and Assessment*, *27*(4), 553-569. https://doi.org/10.1007/s10666-022-09826-5

Herold, N., Schöning, I., Gutknecht, J., Alt, F., Boch, S., Müller, J., Oelmann, Y., Socher, S. A., Wilcke, W., Wubet, T., & Schrumpf, M. (2014). Soil property and management effects on grassland microbial communities across a latitudinal gradient in Germany. *Applied Soil Ecology*, *73*, 41-50. https://doi.org/https://doi.org/10.1016/j.apsoil.2013.07.009

Hinkel, J., Nicholls, R. J., Tol, R. S. J., Wang, Z. B., Hamilton, J. M., Boot, G., Vafeidis, A. T., McFadden, L., Ganopolski, A., & Klein, R. J. T. (2013). A global analysis of erosion of sandy beaches and sea-level rise: An application of DIVA. *Global and Planetary Change*, *111*, 150-158. https://doi.org/https://doi.org/10.1016/j.gloplacha.2013.09.002

Hlavinka, P., Kersebaum, K. C., Dubrovský, M., Fischer, M., Pohanková, E., Balek, J., Žalud, Z., & Trnka, M. (2015). Water balance, drought stress and yields for rainfed field crop rotations under present and future conditions in the Czech Republic [Article]. *Climate Research*, *65*, 175-192. https://doi.org/10.3354/cr01339

Hoogland, T., van den Akker, J. J. H., & Brus, D. J. (2012). Modeling the subsidence of peat soils in the Dutch coastal area. *Geoderma*, *171-172*, 92-97. https://doi.org/https://doi.org/10.1016/j.geoderma.2011.02.013

Horion, S., Ivits, E., De Keersmaecker, W., Tagesson, T., Vogt, J., & Fensholt, R. (2019). Mapping European ecosystem change types in response to land-use change, extreme climate events, and land degradation. *Land Degradation & Development*, *30*(8), 951-963. https://doi.org/10.1002/ldr.3282

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities [Review]. *Science of The Total Environment*, *586*, 127-141. https://doi.org/10.1016/j.scitotenv.2017.01.190

Horváth, A., Csáki, P., Szita, R., Kalicz, P., Gribovszki, Z., Bidló, A., Bolodár-Varga, B., Balázs, P., & Winkler, D. (2021). A complex soil ecological approach in a sustainable urban environment: Soil properties and soil biological quality [Article]. *Minerals*, *11*(7), Article 704. https://doi.org/10.3390/min11070704

Huusko, K., Tarvainen, O., Saravesi, K., Pennanen, T., Fritze, H., Kubin, E., & Markkola, A. (2015). Short-term impacts of energy wood harvesting on ectomycorrhizal fungal communities of Norway spruce saplings. *ISME J*, *9*(3), 581-591. https://doi.org/10.1038/ismej.2014.154

Ilieva, R. T., Cohen, N., Israel, M., Specht, K., Fox-Kämper, R., Fargue-Lelièvre, A., Poniży, L., Schoen, V., Caputo, S., Kirby, C. K., Goldstein, B., Newell, J. P., & Blythe, C. (2022). The Socio-Cultural Benefits of Urban Agriculture: A Review of the Literature. *Land*, *11*(5).

Ingrisch, J., Karlowsky, S., Anadon-Rosell, A., Hasibeder, R., König, A., Augusti, A., Gleixner, G., & Bahn, M. (2018). Land Use Alters the Drought Responses of Productivity and CO2 Fluxes in Mountain Grassland. *Ecosystems*, *21*(4), 689-703. https://doi.org/10.1007/s10021-017-0178-0

Ingrisch, J., Karlowsky, S., Hasibeder, R., Gleixner, G., & Bahn, M. (2020). Drought and recovery effects on belowground respiration dynamics and the partitioning of recent carbon in managed and abandoned grassland. *Global Change Biology*, *26*(8), 4366-4378. https://doi.org/https://doi.org/10.1111/gcb.15131

ISO. (2015). ISO 11074 Soil quality — Vocabulary. In.

Jaligot, R., & Chenal, J. (2019). Stakeholders' perspectives to support the integration of ecosystem services in spatial planning in Switzerland [Article]. *Environments - MDPI*, *6*(8), Article 88. https://doi.org/10.3390/environments6080088

Jarvis, N., Koestel, J., & Larsbo, M. (2016). Understanding Preferential Flow in the Vadose Zone: Recent Advances and Future Prospects. *Vadose Zone Journal*, *15*(12), vzj2016.2009.0075. https://doi.org/https://doi.org/10.2136/vzj2016.09.0075

Jeong, J. S. (2018). Design of spatial PGIS-MCDA-based land assessment planning for identifying sustainable land-use adaptation priorities for climate change impacts [Article]. *Agricultural Systems*, *167*, 61-71. https://doi.org/10.1016/j.agsy.2018.09.001

Johansen, L., Taugourdeau, S., Hovstad, K. A., & Wehn, S. (2019). Ceased grazing management changes the ecosystem services of semi-natural grasslands. *Ecosystems and People*, *15*(1), 192-203. https://doi.org/10.1080/26395916.2019.1644534

Jones, G. V. (2016). Grapevines in a changing environment: A global perspective. In *Grapevine in a Changing Environment: A Molecular and Ecophysiological Perspective* (pp. 1-17). https://doi.org/10.1002/9781118735985.ch1

Jones, N., de Graaff, J., Rodrigo, I., & Duarte, F. (2011). Historical review of land use changes in Portugal (before and after EU integration in 1986) and their implications for land degradation and conservation, with a focus on Centro and Alentejo regions [Article]. *Applied Geography*, *31*(3), 1036-1048. https://doi.org/10.1016/j.apgeog.2011.01.024

Jónsson, J. Ö. G., & Davíðsdóttir, B. (2016). Classification and valuation of soil ecosystem services. *Agricultural Systems*, *145*, 24-38. https://doi.org/https://doi.org/10.1016/j.agsy.2016.02.010

Josefsson, J., Berg, Å., Hiron, M., Pärt, T., & Eggers, S. (2017). Sensitivity of the farmland bird community to crop diversification in Sweden: does the CAP fit? [Article]. *Journal of Applied Ecology*, *54*(2), 518-526. https://doi.org/10.1111/1365-2664.12779

Jóźwik, B., Gavryshkiv, A.-V., & Galewska, K. (2022). Do Urbanization and Energy Consumption Change the Role in Environmental Degradation in the European Union Countries? *Energies*, *15*(17).

Kahlenborn, W., Porst, L., Voss adelphi, M., Fritsch, U., Renner, K., Zebisch, M., Wolf, M., Schönthaler, K., & Schauser, I. (2021). *Climate Impact and Risk Assessment 2021 for Germany* (CLIMATE CHANGE, Issue. https://www.umweltbundesamt.de/publikationen/KWRA-English-Summary

Kaiser, K., Schneider, T., Küster, M., Dietze, E., Fülling, A., Heinrich, S., Kappler, C., Nelle, O., Schult, M., Theuerkauf, M., Vogel, S., de Boer, A. M., Börner, A., Preusser, F., Schwabe, M., Ulrich, J., Wirner, M., & Bens, O. (2020). Palaeosols and their cover sediments of a glacial landscape in northern central Europe: Spatial distribution, pedostratigraphy and evidence on landscape evolution. *Catena*, *193*, 104647. https://doi.org/https://doi.org/10.1016/j.catena.2020.104647

Kammann, C., Ippolito, J., Hagemann, N., Borchard, N., Cayuela, M. L., Estavillo, J. M., Fuertes-Mendizabal, T., Jeffery, S., Kern, J., Novak, J., Rasse, D., Saarnio, S., Schmidt, H. P., Spokas, K., & Wrage-Mönnig, N. (2017). Biochar as a tool to reduce the agricultural greenhouse-gas burden–knowns, unknowns and future research needs [Review]. *Journal of Environmental Engineering and Landscape Management*, *25*(2), 114-139. https://doi.org/10.3846/16486897.2017.1319375

Karamesouti, M., Kairis, O., Gasparatos, D., & Lakes, T. (2023). Map-based soil crusting susceptibility assessment using pedotransfer Rules, CORINE and NDVI: A preliminary study in Greece. *Ecological Indicators*, *154*, 110668. https://doi.org/https://doi.org/10.1016/j.ecolind.2023.110668

Karamesouti, M., Panagos, P., & Kosmas, C. (2018). Model-based spatio-temporal analysis of land desertification risk in Greece. *Catena*, *167*, 266-275. https://doi.org/https://doi.org/10.1016/j.catena.2018.04.042

Karimi, B., Villerd, J., Dequiedt, S., Terrat, S., Chemidlin-Prévost Bouré, N., Djemiel, C., Lelièvre, M., Tripied, J., Nowak, V., Saby, N. P. A., Bispo, A., Jolivet, C., Arrouays, D., Wincker, P., Cruaud, C., & Ranjard, L. (2020). Biogeography of soil microbial habitats

across France. *Global Ecology and Biogeography*, *29*(8), 1399-1411. https://doi.org/https://doi.org/10.1111/geb.13118
Kastridis, A., & Kamperidou, V. (2015). Influence of land use changes on alluviation of Volvi Lake wetland (North Greece). *Soil and Water Research*, *10*(2), 121-129. https://swr.agriculturejournals.cz/artkey/swr-201502-0008.php

http://dx.doi.org/10.17221/174/2014-SWR
Kath, J., Le Brocque, A. F., Reardon-Smith, K., & Apan, A. (2019). Remotely sensed agricultural grassland productivity responses to land use and hydro-climatic drivers under extreme drought and rainfall [Article]. *Agricultural and Forest Meteorology*, *268*, 11-22. https://doi.org/10.1016/j.agrformet.2019.01.007
Keil, D., Niklaus, P. A., von Riedmatten, L. R., Boeddinghaus, R. S., Dormann, C. F., Scherer-Lorenzen, M., Kandeler, E., & Marhan, S. (2015). Effects of warming and drought on potential N2O emissions and denitrifying bacteria abundance in grasslands with different land-use. *FEMS Microbiology Ecology*, *91*(7), fiv066. https://doi.org/10.1093/femsec/fiv066
Keller, B., Szabó, J., Centeri, C., Jakab, G., & Szalai, Z. (2019). Different land-use intensities and their susceptibility to soil erosion. *Agrokémia és Talajtan Agrokem*, *68*(Supplement), 14-23. https://doi.org/https://doi.org/10.1556/0088.2018.00004
Kempf, M. (2023). Enhanced trends in spectral greening and climate anomalies across Europe. *Environ Monit Assess*, *195*(2), 260. https://doi.org/10.1007/s10661-022-10853-8
Kim, S., Axelsson, E. P., Girona, M. M., & Senior, J. K. (2021). Continuous-cover forestry maintains soil fungal communities in Norway spruce dominated boreal forests. *Forest Ecology and Management*, *480*, 118659. https://doi.org/https://doi.org/10.1016/j.foreco.2020.118659
Kimberley, S., Naughton, O., Johnston, P., Gill, L., & Waldren, S. (2012). The influence of flood duration on the surface soil properties and grazing management of karst wetlands (turloughs) in Ireland. *Hydrobiologia*, *692*(1), 29-40. https://doi.org/10.1007/s10750-012-1000-9
Kirchmann, H., Börjesson, G., Kätterer, T., & Cohen, Y. (2017). From agricultural use of sewage sludge to nutrient extraction: A soil science outlook [Article]. *Ambio*, *46*(2), 143-154. https://doi.org/10.1007/s13280-016-0816-3
Klaus, V. H., Kleinebecker, T., Busch, V., Fischer, M., Hölzel, N., Nowak, S., Prati, D., Schäfer, D., Schöning, I., Schrumpf, M., & Hamer, U. (2018). Land use intensity, rather than plant species richness, affects the leaching risk of multiple nutrients from permanent grasslands. *Global Change Biology*, *24*(7), 2828-2840. https://doi.org/https://doi.org/10.1111/gcb.14123
Kleinen, T., & Brovkin, V. (2018). Pathway-dependent fate of permafrost region carbon. *Environmental Research Letters*, *13*(9). https://doi.org/10.1088/1748-9326/aad824
Kolasa-Więcek, A. (2015). Modelling of GHGs in livestock farms and its significance. In *Climate Change Impact on Livestock: Adaptation and Mitigation* (pp. 347-355). https://doi.org/10.1007/978-81-322-2265-1_21
Kolodezhna, V. (2023). *Soil metamorphosis: Ukrainian study of war impacts on soils*. Ukraine War Environmental Consequences Work Group. Retrieved 24 January from https://uwecworkgroup.info/soil-metamorphosis-ukrainian-study-of-war-impacts-on-soils/
Kopittke, G. R., Tietema, A., & Verstraten, J. M. (2012). Soil acidification occurs under ambient conditions but is retarded by repeated drought: Results of a field-scale climate manipulation experiment. *Science of The Total Environment*, *439*, 332-342. https://doi.org/https://doi.org/10.1016/j.scitotenv.2012.09.044
Korboulewsky, N., Perez, G., & Chauvat, M. (2016). How tree diversity affects soil fauna diversity: A review. *Soil Biology and Biochemistry*, *94*, 94-106. https://doi.org/10.1016/j.soilbio.2015.11.024

Kosmas, C., Detsis, V., Karamesouti, M., Kounalaki, K., Vassiliou, P., & Salvati, L. (2015). Exploring Long-Term Impact of Grazing Management on Land Degradation in the Socio-Ecological System of Asteroussia Mountains, Greece. *Land*, *4*(3), 541-559.

Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2019). *Updated CLC illustrated nomenclature guidelines*.

Kourgialas, N. N. (2021). A critical review of water resources in Greece: The key role of agricultural adaptation to climate-water effects [Review]. *Science of The Total Environment*, *775*, Article 145857. https://doi.org/10.1016/j.scitotenv.2021.145857

Kuhlman, T., Diogo, V., & Koomen, E. (2013). Exploring the potential of reed as a bioenergy crop in the Netherlands [Article]. *Biomass and Bioenergy*, *55*, 41-52. https://doi.org/10.1016/j.biombioe.2012.06.024

Lacalle, R. G., Gómez-Sagasti, M. T., Artetxe, U., Garbisu, C., & Becerril, J. M. (2018). Brassica napus has a key role in the recovery of the health of soils contaminated with metals and diesel by rhizoremediation. *Science of The Total Environment*, *618*, 347-356. https://doi.org/https://doi.org/10.1016/j.scitotenv.2017.10.334

Lal, R. (2010). Managing soils for a warming earth in a food-insecure and energy-starved world [Article]. *Journal of Plant Nutrition and Soil Science*, *173*(1), 4-15. https://doi.org/10.1002/jpln.200900290

Lal, R., Safriel, U., & Boer, B. (2012). *Zero Net Land Degradation: A New Sustainable Development Goal for Rio+ 20*.

Landré, A., Cornu, S., Meunier, J. D., Guerin, A., Arrouays, D., Caubet, M., Ratié, C., & Saby, N. P. A. (2020). Do climate and land use affect the pool of total silicon concentration? A digital soil mapping approach of French topsoils. *Geoderma*, *364*, 114175. https://doi.org/https://doi.org/10.1016/j.geoderma.2020.114175

Lavorel, S., Bayer, A., Bondeau, A., Lautenbach, S., Ruiz-Frau, A., Schulp, N., Seppelt, R., Verburg, P., Teeffelen, A. v., Vannier, C., Arneth, A., Cramer, W., & Marba, N. (2017). Pathways to bridge the biophysical realism gap in ecosystem services mapping approaches. *Ecological Indicators*, *74*, 241-260. https://doi.org/https://doi.org/10.1016/j.ecolind.2016.11.015

Le Guern, C., Baudouin, V., Sauvaget, B., Delayre, M., & Conil, P. (2018). A typology of anthropogenic deposits as a tool for modeling urban subsoil geochemistry: example of the Ile de Nantes (France). *Journal of Soils and Sediments*, *18*(2), 373-379. https://doi.org/10.1007/s11368-016-1594-z

Lees, K. J., Quaife, T., Artz, R. R. E., Khomik, M., & Clark, J. M. (2018). Potential for using remote sensing to estimate carbon fluxes across northern peatlands – A review. *Science of The Total Environment*, *615*, 857-874. https://doi.org/https://doi.org/10.1016/j.scitotenv.2017.09.103

Lehmler, S., Förster, M., & Frick, A. (2023). Modelling Green Volume Using Sentinel-1, -2, PALSAR-2 Satellite Data and Machine Learning for Urban and Semi-Urban Areas in Germany. *Environmental Management*, *72*(3), 657-670. https://doi.org/10.1007/s00267-023-01826-9

Leitinger, G., Ruggenthaler, R., Hammerle, A., Lavorel, S., Schirpke, U., Clement, J.-C., Lamarque, P., Obojes, N., & Tappeiner, U. (2015). Impact of droughts on water provision in managed alpine grasslands in two climatically different regions of the Alps. *Ecohydrology*, *8*(8), 1600-1613. https://doi.org/https://doi.org/10.1002/eco.1607

Lelli, C., Chiarucci, A., Tomaselli, M., Di Musciano, M., Lasen, C., Poloniato, G., & Nascimbene, J. (2023). Temporal beta diversity patterns reveal global change impacts in closed mountain grasslands. *Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology*, *157*(2), 233-242. https://doi.org/10.1080/11263504.2022.2100498

Leppik, E., Jüriado, I., Suija, A., & Liira, J. (2013). The conservation of ground layer lichen communities in alvar grasslands and the relevance of substitution habitats. *Biodiversity and Conservation*, *22*(3), 591-614. https://doi.org/10.1007/s10531-012-0430-z

Leppik, E., Jüriado, I., Suija, A., & Liira, J. (2015). Functional ecology of rare and common epigeic lichens in alvar grasslands. *Fungal Ecology*, *13*, 66-76. https://doi.org/https://doi.org/10.1016/j.funeco.2014.08.003

Levers, C., Butsic, V., Verburg, P. H., Müller, D., & Kuemmerle, T. (2016). Drivers of changes in agricultural intensity in Europe [Article]. *Land Use Policy*, *58*, 380-393. https://doi.org/10.1016/j.landusepol.2016.08.013

Libessart, G., Franck-Néel, C., Branchu, P., & Schwartz, C. (2022). The human factor of pedogenesis described by historical trajectories of land use: The case of Paris. *Landscape and Urban Planning*, *222*, 104393. https://doi.org/https://doi.org/10.1016/j.landurbplan.2022.104393

Lilleskov, E. A., Kuyper, T. W., Bidartondo, M. I., & Hobbie, E. A. (2019). Atmospheric nitrogen deposition impacts on the structure and function of forest mycorrhizal communities: A review. *Environ Pollut*, *246*, 148-162. https://doi.org/10.1016/j.envpol.2018.11.074

Löbmann, M. T., Maring, L., Prokop, G., Brils, J., Bender, J., Bispo, A., & Helming, K. (2022). Systems knowledge for sustainable soil and land management. *Science of The Total Environment*, *822*, 153389. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.153389

Lopez-Sangil, L., Rousk, J., Wallander, H., & Casals, P. (2011). Microbial growth rate measurements reveal that land-use abandonment promotes a fungal dominance of SOM decomposition in grazed Mediterranean ecosystems. *Biology and Fertility of Soils*, *47*(2), 129-138. https://doi.org/10.1007/s00374-010-0510-8

Lugato, E., Bampa, F., Panagos, P., Montanarella, L., & Jones, A. (2014). Potential carbon sequestration of European arable soils estimated by modelling a comprehensive set of management practices [Article]. *Global Change Biology*, *20*(11), 3557-3567. https://doi.org/10.1111/gcb.12551

Lugato, E., Paniagua, L., Jones, A., De Vries, W., & Leip, A. (2017). Complementing the topsoil information of the Land Use/Land Cover Area Frame Survey (LUCAS) with modelled N2O emissions [Article]. *PLOS ONE*, *12*(4), Article e0176111. https://doi.org/10.1371/journal.pone.0176111

Lupp, G., Steinhäußer, R., Bastian, O., & Syrbe, R. U. (2015). Impacts of increasing bioenergy use on ecosystem services on nature and society exemplified in the German district of Görlitz [Article]. *Biomass and Bioenergy*, *83*, 131-140. https://doi.org/10.1016/j.biombioe.2015.09.006

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J. I., Paracchini, M. L., Abdul Malak, D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A. M., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A. I., . . . Santos-Martín, F. (2020). *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment* (EUR 30161 EN). (JRC Science for policy report, Issue. P. O. o. t. E. Union.

Maetens, W., Vanmaercke, M., Poesen, J., Jankauskas, B., Jankauskiene, G., & Ionita, I. (2012). Effects of land use on annual runoff and soil loss in Europe and the Mediterranean: A meta-analysis of plot data. *Progress in Physical Geography: Earth and Environment*, *36*(5), 599-653. https://doi.org/10.1177/0309133312451303

Malmivaara-Lämsä, M., Hamberg, L., Haapamäki, E., Liski, J., Kotze, D. J., Lehvävirta, S., & Fritze, H. (2008). Edge effects and trampling in boreal urban forest fragments – impacts on the soil microbial community. *Soil Biology and Biochemistry*, *40*(7), 1612-1621. https://doi.org/https://doi.org/10.1016/j.soilbio.2008.01.013

Malone, Z., Berhe, A. A., & Ryals, R. (2023). Impacts of organic matter amendments on urban soil carbon and soil quality: A meta-analysis. *Journal of Cleaner Production*, *419*, 138148. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.138148

Marguí, E., Iglesias, M., Camps, F., Sala, L., & Hidalgo, M. (2016). Long-term use of biosolids as organic fertilizers in agricultural soils: potentially toxic elements occurrence and mobility [Article]. *Environmental Science and Pollution Research*, *23*(5), 4454-4464. https://doi.org/10.1007/s11356-015-5618-9

Marques, M. J., Bienes, R., Cuadrado, J., Ruiz-Colmenero, M., Barbero-Sierra, C., & Velasco, A. (2015). Analysing Perceptions Attitudes and Responses of Winegrowers about Sustainable Land Management in Central Spain [Article]. *Land Degradation and Development*, *26*(5), 458-467. https://doi.org/10.1002/ldr.2355

Martínez-Cortijo, J., & Ruiz-Canales, A. (2018). Effect of heavy metals on rice irrigated fields with waste water in high pH Mediterranean soils: The particular case of the Valencia area in Spain [Article]. *Agricultural Water Management*, *210*, 108-123. https://doi.org/10.1016/j.agwat.2018.07.037

Maruffi, L., Stucchi, L., Casale, F., & Bocchiola, D. (2022). Soil erosion and sediment transport under climate change for Mera River, in Italian Alps of Valchiavenna. *Science of The Total Environment*, *806*, 150651. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.150651

Mathieu, J. A., Hatté, C., Balesdent, J., & Parent, É. (2015). Deep soil carbon dynamics are driven more by soil type than by climate: a worldwide meta-analysis of radiocarbon profiles. *Global Change Biology*, *21*(11), 4278-4292. https://doi.org/https://doi.org/10.1111/gcb.13012

Matías, L., Hidalgo-Galvez, M. D., Cambrollé, J., Domínguez, M. T., & Pérez-Ramos, I. M. (2021). How will forecasted warming and drought affect soil respiration in savannah ecosystems? The role of tree canopy and grazing legacy. *Agricultural and Forest Meteorology*, *304-305*, 108425. https://doi.org/https://doi.org/10.1016/j.agrformet.2021.108425

Meena, M., Yadav, G., Sonigra, P., Nagda, A., Mehta, T., Swapnil, P., Harish, Marwal, A., & Kumar, S. (2023). Multifarious Responses of Forest Soil Microbial Community Toward Climate Change. *Microbial Ecology*, *86*(1), 49-74. https://doi.org/10.1007/s00248-022-02051-3

Meersmans, J., Arrouays, D., Van Rompaey, A. J. J., Pagé, C., De Baets, S., & Quine, T. A. (2016). Future C loss in mid-latitude mineral soils: climate change exceeds land use mitigation potential in France. *Scientific Reports*, *6*(1), 35798. https://doi.org/10.1038/srep35798

Meersmans, J., Martin, M. P., De Ridder, F., Lacarce, E., Wetterlind, J., De Baets, S., Le Bas, C., Louis, B. P., Orton, T. G., Bispo, A., & Arrouays, D. (2012). A novel soil organic C model using climate, soil type and management data at the national scale in France. *Agronomy for Sustainable Development*, *32*(4), 873-888. https://doi.org/10.1007/s13593-012-0085-x

Meyer, S., Leifeld, J., Bahn, M., & Fuhrer, J. (2012). Free and protected soil organic carbon dynamics respond differently to abandonment of mountain grassland. *Biogeosciences*, *9*(2), 853-865. https://doi.org/10.5194/bg-9-853-2012

Meyer, S., Leifeld, J., Bahn, M., & Fuhrer, J. (2012). Land-use change in subalpine grassland soils: Effect on particulate organic carbon fractions and aggregation. *Journal of Plant Nutrition and Soil Science*, *175*(3), 401-409. https://doi.org/https://doi.org/10.1002/jpln.201100220

Meyer, U.-N., Tischer, A., Freitag, M., Klaus, V. H., Kleinebecker, T., Oelmann, Y., Kandeler, E., Hölzel, N., & Hamer, U. (2022). Enzyme kinetics inform about mechanistic changes in tea litter decomposition across gradients in land-use intensity in Central German grasslands. *Science of The Total Environment*, *836*, 155748. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.155748

Mezosi, G., Blanka, V., Bata, T., Ladányi, Z., Kemény, G., & Meyer, B. C. (2016). Assessment of future scenarios for wind erosion sensitivity changes based on ALADIN and REMO regional climate model simulation data [Article]. *Open Geosciences*, *8*(1), 465-477. https://doi.org/10.1515/geo-2016-0033

Midolo, G., Kuss, P., & Wellstein, C. (2021). Land use and water availability drive community-level plant functional diversity of grasslands along a temperature gradient in the Swiss Alps. *Sci Total Environ*, *764*, 142888. https://doi.org/10.1016/j.scitotenv.2020.142888

Minixhofer, P., Scharf, B., Hafner, S., Weiss, O., Henöckl, C., Greiner, M., Room, T., & Stangl, R. (2022). Towards the Circular Soil Concept: Optimization of Engineered Soils for Green Infrastructure Application. *Sustainability*, *14*(2).

Minixhofer, P., Stangl, R., Baumgarten, A., Huber, S., Weigl, M., Tramberend, P., & Zechmeister-Boltenstern, S. (2019). INSPIRATION for Sustainable Soil and Land Use Management in Austria

INSPIRATION für nachhaltiges Boden- und Flächenmanagement in Österreich. *Die Bodenkultur: Journal of Land Management, Food and Environment*, *70*(2), 99-111. https://doi.org/10.2478/boku-2019-0009

Mitincu, C.-G., Grădinaru, S. R., Iojă, I.-C., Hartel, T., van Lierop, M., & Hossu, C.-A. (2023). The public consultation is open: Insights from urban green infrastructure planning in Romania. *Urban Forestry & Urban Greening*, *86*, 127985. https://doi.org/https://doi.org/10.1016/j.ufug.2023.127985

Mohieddinne, H., Brasseur, B., Gallet-Moron, E., Lenoir, J., Spicher, F., Kobaissi, A., & Horen, H. (2022). Assessment of soil compaction and rutting in managed forests through an airborne LiDAR technique. *Land Degradation & Development*, *34*(5), 1558-1569. https://doi.org/10.1002/ldr.4553

Moindjié, I.-A., Pinsard, C., Accatino, F., & Chakir, R. (2022). Interactions between ecosystem services and land use in France: A spatial statistical analysis. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.954655

Molinari, P. (2014). A geographic information system (GIS) with integrated models: a new approach for assessing the vulnerability and risk of desertification in Sardinia (Italy). *Global Bioethics*, *25*(1), 27-41. https://doi.org/10.1080/11287462.2014.894712

Montanarella, L., Pennock, D. J., McKenzie, N., Badraoui, M., Chude, V., Baptista, I., Mamo, T., Yemefack, M., Singh Aulakh, M., Yagi, K., Young Hong, S., Vijarnsorn, P., Zhang, G.-L., Arrouays, D., Black, H., Krasilnikov, P., Sobocká, J., Alegre, J., Henriquez, C. R., . . . Vargas, R. (2016). World's soils are under threat. *Soil*, *2*(1), 79-82. https://doi.org/10.5194/soil-2-79-2016

Mony, C., Landais, Q., Georges, R., Butet, A., Burel, F., Jambon, O., Gouesbet, V., & Ernoult, A. (2022). Effects of connectivity on seed dispersal patterns in hedgerows. *Journal of Vegetation Science*, *33*(1), e13113. https://doi.org/https://doi.org/10.1111/jvs.13113

Morais, T. G., Domingos, T., & Teixeira, R. F. M. (2016). A spatially explicit life cycle assessment midpoint indicator for soil quality in the European Union using soil organic carbon. *The International Journal of Life Cycle Assessment*, *21*(8), 1076-1091. https://doi.org/10.1007/s11367-016-1077-x

Moreno-García, M., de Torres, M. Á. R. R., Carbonell-Bojollo, R., López-Tirado, J., Aguado-Martín, L. Ó., Rodríguez-Lizana, A., & Ordóñez-Fernández, R. (2021). Effects of multifunctional margins implementation on biodiversity in annual crops [Article]. *Agronomy*, *11*(11), Article 2171. https://doi.org/10.3390/agronomy11112171

Mueller, L., Schindler, U., Mirschel, W., Graham Shepherd, T., Ball, B. C., Helming, K., Rogasik, J., Eulenstein, F., & Wiggering, H. (2010). Assessing the productivity function of soils. A review [Review]. *Agronomy for Sustainable Development*, *30*(3), 601-614. https://doi.org/10.1051/agro/2009057

Múgica, L., Canals, R. M., & San Emeterio, L. (2018). Changes in soil nitrogen dynamics caused by prescribed fires in dense gorse lands in SW Pyrenees. *Sci Total Environ*, *639*, 175-185. https://doi.org/10.1016/j.scitotenv.2018.05.139

Munafò, M. (2022). *Consumo di suolo, dinamiche territoriali e servizi ecosistemici*. https://www.snpambiente.it/wp-content/uploads/2022/07/Rapporto_consumo_di_suolo_2022.pdf

Naipal, V., Lauerwald, R., Ciais, P., Guenet, B., & Wang, Y. (2020). CE-DYNAM (v1): a spatially explicit process-based carbon erosion scheme for use in Earth system models. *Geoscientific Model Development*, *13*(3), 1201-1222. https://doi.org/10.5194/gmd-13-1201-2020

Nandal, A., Yadav, S. S., Rao, A. S., Meena, R. S., & Lal, R. (2023). Advance methodological approaches for carbon stock estimation in forest ecosystems. *Environ Monit Assess*, *195*(2), 315. https://doi.org/10.1007/s10661-022-10898-9

Napoleone, F., Giarrizzo, E., Burrascano, S., & Bartha, S. (2021). Habitat conservation state and plant diversity respond to different drivers in semi-natural grasslands. *Journal of Vegetation Science*, *32*(4). https://doi.org/10.1111/jvs.13055

Navarro Pedreño, J., Meléndez-Pastor, I., & Gómez Lucas, I. (2012). Impact of three decades of urban growth on soil resources in elche (Alicante, Spain) [Article]. *Spanish Journal of Soil Science*, *2*(1), 55-69. https://doi.org/10.3232/SJSS.2012.V2.N1.04

Nitsch, H., Osterburg, B., Roggendorf, W., & Laggner, B. (2012). Cross compliance and the protection of grassland – Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. *Land Use Policy*, *29*(2), 440-448. https://doi.org/https://doi.org/10.1016/j.landusepol.2011.09.001

Nordfjell, T., Björheden, R., Thor, M., & Wästerlund, I. (2010). Changes in technical performance, mechanical availability and prices of machines used in forest operations in Sweden from 1985 to 2010. *Scandinavian Journal of Forest Research*, *25*(4), 382-389. https://doi.org/10.1080/02827581.2010.498385

Norris, J., Matzdorf, B., Barghusen, R., Schulze, C., & van Gorcum, B. (2021). Viewpoints on cooperative peatland management: Expectations and motives of dutch farmers [Article]. *Land*, *10*(12), Article 1326. https://doi.org/10.3390/land10121326

Notebaert, B., Verstraeten, G., Ward, P., Renssen, H., & Van Rompaey, A. (2011). Modeling the sensitivity of sediment and water runoff dynamics to Holocene climate and land use changes at the catchment scale. *Geomorphology*, *126*(1), 18-31. https://doi.org/https://doi.org/10.1016/j.geomorph.2010.08.016

Nougues, L., & Brils, J. (2023). *Soil health ontology aimed to facilitate stakeholder engagement in the achievement in the of the soil mission*

Nunes, A. N., de Almeida, A. C., & Coelho, C. O. A. (2011). Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. *Applied Geography*, *31*(2), 687-699. https://doi.org/https://doi.org/10.1016/j.apgeog.2010.12.006

O'Riordan, R., Davies, J., Stevens, C., Quinton, J. N., & Boyko, C. (2021). The ecosystem services of urban soils: A review. *Geoderma*, *395*, 115076. https://doi.org/https://doi.org/10.1016/j.geoderma.2021.115076

Oliveira, E., Tobias, S., & Hersperger, A. M. (2018). Can Strategic Spatial Planning Contribute to Land Degradation Reduction in Urban Regions? State of the Art and Future Research. *Sustainability*, *10*(4).

Ondrasek, G., & Rengel, Z. (2021). Environmental salinization processes: Detection, implications & solutions [Review]. *Science of The Total Environment*, *754*, Article 142432. https://doi.org/10.1016/j.scitotenv.2020.142432

Ooi, Q. E., Nguyen, C. T. T., Laloo, A., Bandla, A., & Swarup, S. (2022). Urban Soil Microbiome Functions and Their Linkages with Ecosystem Services. In A. Rakshit, S. Ghosh, V. Vasenev, H. Pathak, & V. D. Rajput (Eds.), *Soils in Urban Ecosystem* (pp. 47-63). Springer Singapore. https://doi.org/10.1007/978-981-16-8914-7_4

Orgiazzi, A., Panagos, P., Fernández-Ugalde, O., Wojda, P., Labouyrie, M., Ballabio, C., Franco, A., Pistocchi, A., Montanarella, L., & Jones, A. (2022). LUCAS Soil Biodiversity and LUCAS Soil Pesticides, new tools for research and policy development [Article]. *European Journal of Soil Science*, *73*(5), Article e13299. https://doi.org/10.1111/ejss.13299

Otte, P., Maring, L., De Cleen, M., & Boekhold, S. (2012). Transition in soil policy and associated knowledge development. *Current Opinion in Environmental Sustainability*, *4*(5), 565-572. https://doi.org/https://doi.org/10.1016/j.cosust.2012.09.006

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Panagos, P., Ballabio, C., Meusburger, K., Spinoni, J., Alewell, C., & Borrelli, P. (2017). Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets. *Journal of Hydrology*, *548*, 251-262. https://doi.org/https://doi.org/10.1016/j.jhydrol.2017.03.006

Panagos, P., Borrelli, P., Matthews, F., Liakos, L., Bezak, N., Diodato, N., & Ballabio, C. (2022). Global rainfall erosivity projections for 2050 and 2070 [Article]. *Journal of Hydrology*, *610*, Article 127865. https://doi.org/10.1016/j.jhydrol.2022.127865

Panagos, P., Imeson, A., Meusburger, K., Borrelli, P., Poesen, J., & Alewell, C. (2016). Soil Conservation in Europe: Wish or Reality? [Article]. *Land Degradation and Development*, *27*(6), 1547-1551. https://doi.org/10.1002/ldr.2538

Panagos, P., & Katsoyiannis, A. (2019). Soil erosion modelling: The new challenges as the result of policy developments in Europe [Editorial]. *Environmental Research*, *172*, 470-474. https://doi.org/10.1016/j.envres.2019.02.043

Panagos, P., Muntwyler, A., Liakos, L., Borrelli, P., Biavetti, I., Bogonos, M., & Lugato, E. (2022). Phosphorus plant removal from European agricultural land [Article]. *Journal fur Verbraucherschutz und Lebensmittelsicherheit*, *17*(1), 5-20. https://doi.org/10.1007/s00003-022-01363-3

Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervas, J., Jones, A., & Montanarella, L. (2022). European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies. *European Journal of Soil Science*, *73*(6), e13315. https://doi.org/https://doi.org/10.1111/ejss.13315

Panagos, P., Van Liedekerke, M., Yigini, Y., & Montanarella, L. (2013). Contaminated Sites in Europe: Review of the Current Situation Based on Data Collected through a European Network. *Journal of Environmental and Public Health*, *2013*, 158764. https://doi.org/10.1155/2013/158764

Pansu, J., De Danieli, S., Puissant, J., Gonzalez, J.-M., Gielly, L., Cordonnier, T., Zinger, L., Brun, J.-J., Choler, P., Taberlet, P., & Cécillon, L. (2015). Landscape-scale distribution patterns of earthworms inferred from soil DNA. *Soil Biology and Biochemistry*, *83*, 100-105. https://doi.org/https://doi.org/10.1016/j.soilbio.2015.01.004

Papadopoulos, A., Kalivas, D., Hatzichristos, T., & Abakumov, E. (2011). Decision support system for nitrogen fertilization using fuzzy theory [Article]. *Computers and Electronics in Agriculture*, *78*(2), 130-139. https://doi.org/10.1016/j.compag.2011.06.007

Pardo, G., Martin-Garcia, I., Arco, A., Yañez-Ruiz, D. R., Moral, R., & Del Prado, A. (2016). Greenhouse-gas mitigation potential of agro-industrial by-products in the diet of dairy goats in Spain: A life-cycle perspective. Animal Production Science,

Parras-Alcántara, L., Martín-Carrillo, M., & Lozano-García, B. (2013). Impacts of land use change in soil carbon and nitrogen in a Mediterranean agricultural area (Southern Spain) [Article]. *Solid Earth*, *4*(1), 167-177. https://doi.org/10.5194/se-4-167-2013

Patriche, C. V. (2023). Applying RUSLE for soil erosion estimation in Romania under current and future climate scenarios. *Geoderma Regional*, *34*, e00687. https://doi.org/https://doi.org/10.1016/j.geodrs.2023.e00687

Paul, S., & Rakshit, A. (2022). Classification and Functional Characteristics of Urban Soil. In A. Rakshit, S. Ghosh, V. Vasenev, H. Pathak, & V. D. Rajput (Eds.), *Soils in Urban Ecosystem* (pp. 11-23). Springer Singapore. https://doi.org/10.1007/978-981-16-8914-7_2

Peco, B., Carmona, C. P., de Pablos, I., & Azcárate, F. M. (2012). Effects of grazing abandonment on functional and taxonomic diversity of Mediterranean grasslands. *Agriculture, Ecosystems & Environment*, *152*, 27-32. https://doi.org/https://doi.org/10.1016/j.agee.2012.02.009

Peng, J., Niesel, J., & Loew, A. (2015). Evaluation of soil moisture downscaling using a simple thermal-based proxy-the REMEDHUS network (Spain) example [Article]. *Hydrology and Earth System Sciences*, *19*(12), 4765-4782. https://doi.org/10.5194/hess-19-4765-2015

Pereira, P., Barceló, D., & Panagos, P. (2020). Soil and water threats in a changing environment [Note]. *Environmental Research*, *186*, Article 109501. https://doi.org/10.1016/j.envres.2020.109501

Perović, V., Kadović, R., Djurdjević, V., Braunović, S., Čakmak, D., Mitrović, M., & Pavlović, P. (2019). Effects of changes in climate and land use on soil erosion: a case study of the Vranjska Valley, Serbia. *Regional Environmental Change*, *19*(4), 1035-1046. https://doi.org/10.1007/s10113-018-1456-x

Perpiña Castillo, C., Coll Aliaga, E., Lavalle, C., & Martínez Llario, J. C. (2020). An Assessment and Spatial Modelling of Agricultural Land Abandonment in Spain (2015–2030). *Sustainability*, *12*(2), 560. https://doi.org/10.3390/su12020560

Petropoulos, G. P., Ireland, G., & Barrett, B. (2015). Surface soil moisture retrievals from remote sensing: Current status, products & future trends [Review]. *Physics and Chemistry of the Earth*, *83-84*, 36-56. https://doi.org/10.1016/j.pce.2015.02.009

Petrova, S., Nikolov, B., Velcheva, I., Angelov, N., Valcheva, E., Katova, A., Golubinova, I., & Marinov-Serafimov, P. (2022). Buffer Green Patches around Urban Road Network as a Tool for Sustainable Soil Management. *Land*, *11*(3).

Picchio, R., Neri, F., Petrini, E., Verani, S., Marchi, E., & Certini, G. (2012). Machinery-induced soil compaction in thinning two pine stands in central Italy. *Forest Ecology and Management*, *285*, 38-43. https://doi.org/10.1016/j.foreco.2012.08.008

Piirainen, S., Finér, L., Mannerkoski, H., & Starr, M. (2007). Carbon, nitrogen and phosphorus leaching after site preparation at a boreal forest clear-cut area. *Forest Ecology and Management*, *243*(1), 10-18. https://doi.org/https://doi.org/10.1016/j.foreco.2007.01.053

Pirastru, M., Bagarello, V., Iovino, M., Marrosu, R., Castellini, M., Giadrossich, F., & Niedda, M. (2017). Subsurface flow and large-scale lateral saturated soil hydraulic conductivity in a Mediterranean hillslope with contrasting land uses. *Journal of Hydrology and Hydromechanics*, *65*(3), 297-306. https://doi.org/10.1515/johh-2017-0006

Pivato, A., Vanin, S., Raga, R., Lavagnolo, M. C., Barausse, A., Rieple, A., Laurent, A., & Cossu, R. (2016). Use of digestate from a decentralized on-farm biogas plant as fertilizer in soils: An ecotoxicological study for future indicators in risk and life cycle assessment [Article]. *Waste Management*, *49*, 378-389. https://doi.org/10.1016/j.wasman.2015.12.009

Piveteau, P., Druilhe, C., & Aissani, L. (2022). What on earth? The impact of digestates and composts from farm effluent management on fluxes of foodborne pathogens in agricultural lands [Review]. *Science of The Total Environment*, *840*, Article 156693. https://doi.org/10.1016/j.scitotenv.2022.156693

Podmanicky, L., Balázs, K., Belényesi, M., Centeri, C., Kristóf, D., & Kohlheb, N. (2011). Modelling soil quality changes in Europe. An impact assessment of land use change on soil quality in Europe. *Ecological Indicators*, *11*(1), 4-15. https://doi.org/10.1016/j.ecolind.2009.08.002

Poeplau, C., & Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops - A meta-analysis [Review]. *Agriculture, Ecosystems and Environment*, *200*, 33-41. https://doi.org/10.1016/j.agee.2014.10.024

Poesen, J. (2018). Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms*, *43*(1), 64-84. https://doi.org/https://doi.org/10.1002/esp.4250

Polce, C., Maes, J., Brander, L., Cescatti, A., Baranzelli, C., Lavalle, C., & Zulian, G. (2016). Global change impacts on ecosystem services: a spatially explicit assessment for Europe [10.3897/oneeco.1.e9990]. *One Ecosystem*, *1*, e9990. https://doi.org/10.3897/oneeco.1.e9990

Polykretis, C., Grillakis, M. G., Manoudakis, S., Seiradakis, K. D., & Alexakis, D. D. (2023). Spatial variability of water-induced soil erosion under climate change and land use/cover dynamics: From assessing the past to foreseeing the future in the Mediterranean island of Crete. *Geomorphology*, *439*, 108859. https://doi.org/https://doi.org/10.1016/j.geomorph.2023.108859

Potthoff, K., & Stroth, V. (2016). Patterns of vegetation change on alpine mountain summer farms in norway. *Geografiska Annaler: Series A, Physical Geography*, *93*(3), 163-174. https://doi.org/10.1111/j.1468-0459.2011.00427.x

Prager, K., Hagemann, N., Schuler, J., & Heyn, N. (2011). Incentives and enforcement: The institutional design and policy mix for soil conservation in Brandenburg (Germany) [Article]. *Land Degradation and Development*, *22*(1), 111-123. https://doi.org/10.1002/ldr.1038

Prasuhn, V. (2020). Twenty years of soil erosion on-farm measurement: Annual variation, spatial distribution and the impact of conservation programmes for soil loss rates in Switzerland [Article]. *Earth Surface Processes and Landforms*, *45*(7), 1539-1554. https://doi.org/10.1002/esp.4829

Prokop, G., & Jobstmann, H. (2011). *Report on best practices for limiting soil sealing and mitigating its effects*. https://wayback.archive-it.org/12090/20221007084057/https://ec.europa.eu/environment/archives/soil/pdf/sealing/Soil%20sealing%20-%20Final%20Report.pdf

Pulido-Fernández, M., Schnabel, S., Lavado-Contador, J. F., Miralles Mellado, I., & Ortega Pérez, R. (2013). Soil organic matter of Iberian open woodland rangelands as influenced by vegetation cover and land management. *Catena*, *109*, 13-24. https://doi.org/https://doi.org/10.1016/j.catena.2013.05.002

Pulleman, M., Creamer, R., Hamer, U., Helder, J., Pelosi, C., Pérès, G., & Rutgers, M. (2012). Soil biodiversity, biological indicators and soil ecosystem services—an overview of European approaches. *Current Opinion in Environmental Sustainability*, *4*(5), 529-538. https://doi.org/https://doi.org/10.1016/j.cosust.2012.10.009

Rajbanshi, J., Das, S., & Paul, R. (2023). Quantification of the effects of conservation practices on surface runoff and soil erosion in croplands and their trade-off: A meta-analysis [Review]. *Science of The Total Environment*, *864*, Article 161015. https://doi.org/10.1016/j.scitotenv.2022.161015

Ranjard, L., Dequiedt, S., Jolivet, C., Saby, N. P. A., Thioulouse, J., Harmand, J., Loisel, P., Rapaport, A., Fall, S., Simonet, P., Joffre, R., Bouré, N. C.-P., Maron, P.-A., Mougel, C., Martin, M. P., Toutain, B., Arrouays, D., & Lemanceau, P. (2010). Biogeography of soil microbial communities: a review and a description of the ongoing french national initiative. *Agronomy for Sustainable Development*, *30*(2), 359-365. https://doi.org/10.1051/agro/2009033

Rankinen, K., Peltonen-Sainio, P., Granlund, K., Ojanen, H., Laapas, M., Hakala, K., Sippel, K., Helenius, J., & Forsius, M. (2013). Climate change adaptation in arable land use, and impact on nitrogen load at catchment scale in northern agriculture [Article]. *Agricultural and Food Science*, *22*(3), 342-355. https://doi.org/10.23986/afsci.7500

Redondo, M. A., Boberg, J., Stenlid, J., Oliva, J., & Cheng, L. (2018). Functional traits associated with the establishment of introduced Phytophthora spp. in Swedish forests. *Journal of Applied Ecology*, *55*(3), 1538-1552. https://doi.org/10.1111/1365-2664.13068

Reichenbach, P., Busca, C., Mondini, A. C., & Rossi, M. (2014). The Influence of Land Use Change on Landslide Susceptibility Zonation: The Briga Catchment Test Site (Messina, Italy). *Environmental Management*, *54*(6), 1372-1384. https://doi.org/10.1007/s00267-014-0357-0

Reinsch, S., Ambus, P., Thornton, B., & Paterson, E. (2013). Impact of future climatic conditions on the potential for soil organic matter priming. *Soil Biology and Biochemistry*, *65*, 133-140. https://doi.org/https://doi.org/10.1016/j.soilbio.2013.05.013

Renwick, A., Jansson, T., Verburg, P. H., Revoredo-Giha, C., Britz, W., Gocht, A., & McCracken, D. (2013). Policy reform and agricultural land abandonment in the EU [Article]. *Land Use Policy*, *30*(1), 446-457. https://doi.org/10.1016/j.landusepol.2012.04.005

Revill, A., Sus, O., Barrett, B., & Williams, M. (2013). Carbon cycling of European croplands: A framework for the assimilation of optical and microwave Earth observation data [Article]. *Remote Sensing of Environment*, *137*, 84-93. https://doi.org/10.1016/j.rse.2013.06.002

Ricci, G. F., D'Ambrosio, E., De Girolamo, A. M., & Gentile, F. (2022). Efficiency and feasibility of Best Management Practices to reduce nutrient loads in an agricultural river basin [Article]. *Agricultural Water Management*, *259*, Article 107241. https://doi.org/10.1016/j.agwat.2021.107241

Ries, J. B. (2010). Methodologies for soil erosion and land degradation assessment in mediterranean-type ecosystems. *Land Degradation & Development*, *21*(2), 171-187. https://doi.org/https://doi.org/10.1002/ldr.943

Ristic, R., Radic, B., Vasiljevic, N., & Nikic, Z. (2011). Land use change for flood protection: A prospective study for the restoration of the river Jelasnica watershed. *Glasnik Sumarskog fakulteta*(103), 115-130. https://doi.org/10.2298/gsf1103115r

Robinson, D. T., Murray-Rust, D., Rieser, V., Milicic, V., & Rounsevell, M. (2012). Modelling the impacts of land system dynamics on human well-being: Using an agent-based approach to cope with data limitations in Koper, Slovenia [Article]. *Computers, Environment and Urban Systems*, *36*(2), 164-176. https://doi.org/10.1016/j.compenvurbsys.2011.10.002

Robson, T. M., Baptist, F., Clément, J.-C., & Lavorel, S. (2010). Land use in subalpine grasslands affects nitrogen cycling via changes in plant community and soil microbial uptake dynamics. *Journal of Ecology*, *98*(1), 62-73. https://doi.org/https://doi.org/10.1111/j.1365-2745.2009.01609.x

Rodríguez, A., Iglesias, I., & de la Torre, A. (2022). Prioritisation tool for targeting the monitoring of veterinary pharmaceuticals in soils at a national level: The case of Spain. European Journal of Soil Science,

Romano, N., Nasta, P., Bogena, H., De Vita, P., Stellato, L., & Vereecken, H. (2018). Monitoring Hydrological Processes for Land and Water Resources Management in a Mediterranean Ecosystem: The Alento River Catchment Observatory. *Vadose Zone Journal*, *17*(1), 180042. https://doi.org/https://doi.org/10.2136/vzj2018.03.0042

Rončák, P., & Šurda, P. (2019). Water balance estimation under a changing climate in the Turiec River basin. *Acta Hydrologica Slovaca*, *20 (2)*, 160-165. https://doi.org/https://doi.org/10.31577/ahs-2019-0020.02.0019

Rubio-Delgado, J., Schnabel, S., Gómez-Gutiérrez, Á., & Lavado-Contador, J. F. (2019). Temporal and spatial variation of soil erosion in wooded rangelands of southwest Spain. *Earth Surface Processes and Landforms*, *44*(11), 2141-2155. https://doi.org/https://doi.org/10.1002/esp.4636

Rutgers, M., van Leeuwen, J. P., Vrebos, D., van Wijnen, H. J., Schouten, T., & de Goede, R. G. M. (2019). Mapping Soil Biodiversity in Europe and the Netherlands. *Soil Systems*, *3*(2).

Ryabchenko, O., & Nonhebel, S. (2016). Assessing wheat production futures in the Ukraine [Article]. *Outlook on Agriculture*, *45*(3), 165-172. https://doi.org/10.1177/0030727016664159

Sáenz de Miera, L. E., Pinto, R., Gutierrez-Gonzalez, J. J., Calvo, L., & Ansola, G. (2020). Wildfire effects on diversity and composition in soil bacterial communities. *Science of The Total Environment*, *726*, 138636. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.138636

Saget, S., Costa, M., Barilli, E., Wilton de Vasconcelos, M., Santos, C. S., Styles, D., & Williams, M. (2020). Substituting wheat with chickpea flour in pasta production delivers more nutrition at a lower environmental cost [Article]. *Sustainable Production and Consumption*, *24*, 26-38. https://doi.org/10.1016/j.spc.2020.06.012

Salvati, L., Ferrara, C., & Ranalli, F. (2014). Changes at the fringe: Soil quality and environmental vulnerability during intense urban expansion [Article]. *Eurasian Soil Science*, *47*(10), 1069-1075. https://doi.org/10.1134/S106422931410010X

Salvati, L., Zitti, M., & Perini, L. (2016). Fifty Years on: Long-term Patterns of Land Sensitivity to Desertification in Italy. *Land Degradation & Development*, *27*(2), 97-107. https://doi.org/https://doi.org/10.1002/ldr.2226

Samariks, V., Lazdiņš, A., Bārdule, A., Kalēja, S., Butlers, A., Spalva, G., & Jansons, Ā. (2023). Impact of Former Peat Extraction Field Afforestation on Soil Greenhouse Gas Emissions in Hemiboreal Region. *Forests*, *14*(2).

Samela, C., Imbrenda, V., Coluzzi, R., Pace, L., Simoniello, T., & Lanfredi, M. (2022). Multi-Decadal Assessment of Soil Loss in a Mediterranean Region Characterized by Contrasting Local Climates [Article]. *Land*, *11*(7), Article 1010. https://doi.org/10.3390/land11071010

Santin, C., & Doerr, S. H. (2016). Fire effects on soils: the human dimension. *Philos Trans R Soc Lond B Biol Sci*, *371*(1696). https://doi.org/10.1098/rstb.2015.0171

Santini, A., Ghelardini, L., De Pace, C., Desprez-Loustau, M. L., Capretti, P., Chandelier, A., Cech, T., Chira, D., Diamandis, S., Gaitniekis, T., Hantula, J., Holdenrieder, O., Jankovsky, L., Jung, T., Jurc, D., Kirisits, T., Kunca, A., Lygis, V., Malecka, M., . . . Stenlid, J. (2013). Biogeographical patterns and determinants of invasion by forest pathogens in Europe. *New Phytologist*, *197*(1), 238-250. https://doi.org/https://doi.org/10.1111/j.1469-8137.2012.04364.x

Sardans, J., & Peñuelas, J. (2014). Hydraulic redistribution by plants and nutrient stoichiometry: Shifts under global change. *Ecohydrology*, *7*(1), 1-20. https://doi.org/https://doi.org/10.1002/eco.1459

Sardans, J., & Peñuelas, J. (2015). Potassium: a neglected nutrient in global change. *Global Ecology and Biogeography*, *24*(3), 261-275. https://doi.org/https://doi.org/10.1111/geb.12259

Schibalski, A., Kleyer, M., Maier, M., & Schröder, B. (2022). Spatiotemporally explicit prediction of future ecosystem service provisioning in response to climate change, sea level rise, and adaptation strategies. *Ecosystem Services*, *54*, 101414. https://doi.org/https://doi.org/10.1016/j.ecoser.2022.101414

Schillaci, C., Jones, A., Vieira, D., Munafò, M., & Montanarella, L. (2023). Evaluation of the United Nations Sustainable Development Goal 15.3.1 indicator of land degradation in the European Union. *Land Degradation & Development*, *34*(1), 250-268. https://doi.org/https://doi.org/10.1002/ldr.4457

Schjønning, P., van den Akker, J. J. H., Keller, T., Greve, M. H., Lamandé, M., Simojoki, A., Stettler, M., Arvidsson, J., & Breuning-Madsen, H. (2015). Chapter Five - Driver-Pressure-State-Impact-Response (DPSIR) Analysis and Risk Assessment for Soil Compaction—A European Perspective. In D. L. Sparks (Ed.), *Advances in Agronomy* (Vol. 133, pp. 183-237). Academic Press. https://doi.org/https://doi.org/10.1016/bs.agron.2015.06.001

Schlingmann, M., Tobler, U., Berauer, B., Garcia-Franco, N., Wilfahrt, P., Wiesmeier, M., Jentsch, A., Wolf, B., Kiese, R., & Dannenmann, M. (2020). Intensive slurry management and climate change promote nitrogen mining from organic matter-rich montane grassland soils. *Plant and Soil*, *456*(1-2), 81-98. https://doi.org/10.1007/s11104-020-04697-9

Schnabel, S., Pulido-Fernández, M., & Lavado-Contador, J. F. (2013). Soil water repellency in rangelands of Extremadura (Spain) and its relationship with land management. *Catena*, *103*, 53-61. https://doi.org/https://doi.org/10.1016/j.catena.2011.11.006

Schrautzer, J., Breuer, V., Holsten, B., Jensen, K., & Rasran, L. (2016). Long-term effects of large-scale grazing on the vegetation of a rewetted river valley. *Agriculture, Ecosystems & Environment*, *216*, 207-215. https://doi.org/https://doi.org/10.1016/j.agee.2015.09.036

Schröder, J. J., Ten Berge, H. F. M., Bampa, F., Creamer, R. E., Giraldez-Cervera, J. V., Henriksen, C. B., Olesen, J. E., Rutgers, M., Sandén, T., & Spiegel, H. (2020). Multi-Functional Land Use Is Not Self-Evident for European Farmers: A Critical Review [Review]. *Frontiers in Environmental Science*, *8*, Article 575466. https://doi.org/10.3389/fenvs.2020.575466

Schultz, H. R., & Stoll, M. (2010). Some critical issues in environmental physiology of grapevines: Future challenges and current limitations [Article]. *Australian Journal of Grape and Wine Research*, *16*(SUPPL. 1), 4-24. https://doi.org/10.1111/j.1755-0238.2009.00074.x

Schütte, G., Eckerstorfer, M., Rastelli, V., Reichenbecher, W., Restrepo-Vassalli, S., Ruohonen-Lehto, M., Saucy, A. G. W., & Mertens, M. (2017). Herbicide resistance and biodiversity: agronomic and environmental aspects of genetically modified herbicide-resistant plants [Review]. *Environmental Sciences Europe*, *29*(1), Article 5. https://doi.org/10.1186/s12302-016-0100-y

Scordia, D., Calcagno, S., Piccitto, A., Patanè, C., & Cosentino, S. L. (2020). The impact of soil water content on yield, composition, energy, and water indicators of the bioenergy grass saccharum spontaneum ssp. aegyptiacum under three-growing seasons [Article]. *Agronomy*, *10*(8), Article 1105. https://doi.org/10.3390/agronomy10081105

Seeber, J., Tasser, E., Rubatscher, D., Loacker, I., Lavorel, S., Robson, T. M., Balzarolo, M., Altimir, N., Drösler, M., Vescovo, L., Gamper, S., Barančok, P., Staszewski, T., Wohlfahrt, G., Cernusca, A., Sebastia, M. T., Tappeiner, U., & Bahn, M. (2022). Effects of land use and climate on carbon and nitrogen pool partitioning in European mountain grasslands. *Science of The Total Environment*, *822*, 153380. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.153380

Seifollahi-Aghmiuni, S., Kalantari, Z., Egidi, G., Gaburova, L., & Salvati, L. (2022). Urbanisation-driven land degradation and socioeconomic challenges in peri-urban areas: Insights from Southern Europe. *Ambio*, *51*(6), 1446-1458. https://doi.org/10.1007/s13280-022-01701-7

Serra, P., Giuntoli, J., Agostini, A., Colauzzi, M., & Amaducci, S. (2017). Coupling sorghum biomass and wheat straw to minimise the environmental impact of bioenergy production [Article]. *Journal of Cleaner Production*, *154*, 242-254. https://doi.org/10.1016/j.jclepro.2017.03.208

Shahane, A. A., & Shivay, Y. S. (2021). Soil Health and Its Improvement Through Novel Agronomic and Innovative Approaches [Review]. *Frontiers in Agronomy*, *3*, Article 680456. https://doi.org/10.3389/fagro.2021.680456

Shakesby, R. A. (2011). Post-wildfire soil erosion in the Mediterranean: Review and future research directions. *Earth-Science Reviews*, *105*(3), 71-100. https://doi.org/https://doi.org/10.1016/j.earscirev.2011.01.001

Siebert, J., Ciobanu, M., Schädler, M., & Eisenhauer, N. (2020). Climate change and land use induce functional shifts in soil nematode communities [Article]. *Oecologia*, *192*(1), 281-294. https://doi.org/10.1007/s00442-019-04560-4

Siebert, J., Eisenhauer, N., Poll, C., Marhan, S., Bonkowski, M., Hines, J., Koller, R., Ruess, L., & Thakur, M. P. (2019). Earthworms modulate the effects of climate warming on the taxon richness of soil meso- and macrofauna in an agricultural system [Article]. *Agriculture, Ecosystems and Environment*, *278*, 72-80. https://doi.org/10.1016/j.agee.2019.03.004

Sikorski, P., Gawryszewska, B., Sikorska, D., Chormański, J., Schwerk, A., Jojczyk, A., Ciężkowski, W., Archiciński, P., Łepkowski, M., Dymitryszyn, I., Przybysz, A., Wińska-Krysiak, M., Zajdel, B., Matusiak, J., & Łaszkiewicz, E. (2021). The value of doing nothing – How informal green spaces can provide comparable ecosystem services to cultivated urban parks. *Ecosystem Services*, *50*, 101339. https://doi.org/https://doi.org/10.1016/j.ecoser.2021.101339

Sikorski, P., Szumacher, I., Sikorska, D., Kozak, M., & Wierzba, M. (2013). Effects of visitor pressure on understory vegetation in Warsaw forested parks (Poland). *Environ Monit Assess*, *185*(7), 5823-5836. https://doi.org/10.1007/s10661-012-2987-0

Sil, Â., Fonseca, F., Gonçalves, J., Honrado, J., Marta-Pedroso, C., Alonso, J., Ramos, M., & Azevedo, J. C. (2017). Analysing carbon sequestration and storage dynamics in a changing mountain landscape in Portugal: insights for management and planning. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *13*(2), 82-104. https://doi.org/10.1080/21513732.2017.1297331

Smerald, A., Fuchs, K., Kraus, D., Butterbach-Bahl, K., & Scheer, C. (2022). Significant Global Yield-Gap Closing Is Possible Without Increasing the Intensity of Environmentally Harmful Nitrogen Losses [Article]. *Frontiers in Sustainable Food Systems*, *6*, Article 736394. https://doi.org/10.3389/fsufs.2022.736394

Smiraglia, D., Tombolini, I., Canfora, L., Bajocco, S., Perini, L., & Salvati, L. (2019). The Latent Relationship Between Soil Vulnerability to Degradation and Land Fragmentation: A Statistical Analysis of Landscape Metrics in Italy, 1960–2010. *Environmental Management*, *64*(2), 154-165. https://doi.org/10.1007/s00267-019-01175-6

Smith, P. (2012). Agricultural greenhouse gas mitigation potential globally, in Europe and in the UK: What have we learnt in the last 20 years? [Review]. *Global Change Biology*, *18*(1), 35-43. https://doi.org/10.1111/j.1365-2486.2011.02517.x

Smith, P. (2014). Do grasslands act as a perpetual sink for carbon? *Global Change Biology*, *20*(9), 2708-2711. https://doi.org/https://doi.org/10.1111/gcb.12561

Smolander, A., Törmänen, T., Kitunen, V., & Lindroos, A.-J. (2019). Dynamics of soil nitrogen cycling and losses under Norway spruce logging residues on a clear-cut. *Forest Ecology and Management*, *449*. https://doi.org/10.1016/j.foreco.2019.06.041

Socher, S. A., Prati, D., Boch, S., Müller, J., Klaus, V. H., Hölzel, N., & Fischer, M. (2012). Direct and productivity-mediated indirect effects of fertilization, mowing and grazing on grassland species richness. *Journal of Ecology*, *100*(6), 1391-1399. https://doi.org/https://doi.org/10.1111/j.1365-2745.2012.02020.x

Solinas, S., Tiloca, M. T., Deligios, P. A., Cossu, M., & Ledda, L. (2021). Carbon footprints and social carbon cost assessments in a perennial energy crop system: A comparison of fertilizer management practices in a Mediterranean area [Article]. *Agricultural Systems*, *186*, Article 102989. https://doi.org/10.1016/j.agsy.2020.102989

Souza-Alonso, P., Rodríguez, J., González, L., & Lorenzo, P. (2017). Here to stay. Recent advances and perspectives about Acacia invasion in Mediterranean areas. *Annals of Forest Science*, *74*(3), 55. https://doi.org/10.1007/s13595-017-0651-0

Spiertz, H. (2012). Avenues to meet food security. The role of agronomy on solving complexity in food production and resource use [Review]. *European Journal of Agronomy*, *43*, 1-8. https://doi.org/10.1016/j.eja.2012.04.004

Stals, T., & Ivanovs, J. (2019). Identification of wet areas in agricultural lands using remote sensing data. Research for Rural Development,

Stampfli, A., Bloor, J. M. G., Fischer, M., & Zeiter, M. (2018). High land-use intensity exacerbates shifts in grassland vegetation composition after severe experimental drought. *Global Change Biology*, *24*(5), 2021-2034. https://doi.org/https://doi.org/10.1111/gcb.14046

Stanchi, S., Freppaz, M., Godone, D., & Zanini, E. (2013). Assessing the susceptibility of alpine soils to erosion using soil physical and site indicators. *Soil Use and Management*, *29*(4), 586-596. https://doi.org/https://doi.org/10.1111/sum.12063

Starczewski, T., Rogatka, K., Kukulska-Kozieł, A., Noszczyk, T., & Cegielska, K. (2023). Urban green resilience: Experience from post-industrial cities in Poland. *Geoscience Frontiers*, *14*(4), 101560. https://doi.org/https://doi.org/10.1016/j.gsf.2023.101560

Stefanidis, S., Alexandridis, V., Chatzichristaki, C., & Stefanidis, P. (2021). Assessing Soil Loss by Water Erosion in a Typical Mediterranean Ecosystem of Northern Greece under Current and Future Rainfall Erosivity. *Water*, *13*(15). https://doi.org/10.3390/w13152002

Stefanski, J., Kuemmerle, T., Chaskovskyy, O., Griffiths, P., Havryluk, V., Knorn, J., Korol, N., Sieber, A., & Waske, B. (2014). Mapping land management regimes in western Ukraine using optical and SAR data [Article]. *Remote Sensing*, *6*(6), 5279-5305. https://doi.org/10.3390/rs6065279

Stempfhuber, B., Welzl, G., Wubet, T., Schöning, I., Marhan, S., Buscot, F., Kandeler, E., & Schloter, M. (2014). Drivers for ammonia-oxidation along a land-use gradient in grassland soils. *Soil Biology and Biochemistry*, *69*, 179-186. https://doi.org/https://doi.org/10.1016/j.soilbio.2013.11.007

Stobbelaar, D. J., van der Knaap, W., & Spijker, J. (2021). Greening the City: How to Get Rid of Garden Pavement! The 'Steenbreek' Program as a Dutch Example. *Sustainability*, *13*(6).

Stoorvogel, J. J., Bakkenes, M., Temme, A. J. A. M., Batjes, N. H., & ten Brink, B. J. E. (2017). S-World: A Global Soil Map for Environmental Modelling. *Land Degradation & Development*, *28*(1), 22-33. https://doi.org/https://doi.org/10.1002/ldr.2656

Sušnik, J., Masia, S., Kravčík, M., Pokorný, J., & Hesslerová, P. (2022). Costs and benefits of landscape-based water retention measures as nature-based solutions to mitigating climate impacts in eastern Germany, Czech Republic, and Slovakia [Article]. *Land Degradation and Development*, *33*(16), 3074-3087. https://doi.org/10.1002/ldr.4373

Szukics, U., Grigulis, K., Legay, N., Kastl, E.-M., Baxendale, C., Bardgett, R. D., Clément, J.-C., Lavorel, S., Schloter, M., & Bahn, M. (2019). Management versus site effects on the abundance of nitrifiers and denitrifiers in European mountain grasslands. *Science of The Total Environment*, *648*, 745-753. https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.08.039

Tanneberger, F., Schröder, C., Hohlbein, M., Lenschow, U., Permien, T., Wichmann, S., & Wichtmann, W. (2020). Climate Change Mitigation through Land Use on Rewetted

Peatlands – Cross-Sectoral Spatial Planning for Paludiculture in Northeast Germany [Article]. *Wetlands*, *40*(6), 2309-2320. https://doi.org/10.1007/s13157-020-01310-8

Tarolli, P., & Straffelini, E. (2020). Agriculture in Hilly and Mountainous Landscapes: Threats, Monitoring and Sustainable Management [Article]. *Geography and Sustainability*, *1*(1), 70-76. https://doi.org/10.1016/j.geosus.2020.03.003

Thapa, P., Torralba, M., Buerkert, A., Dittrich, C., & Plieninger, T. (2021). Ecological and social outcomes of urbanization on regional farming systems: A global synthesis [Article]. *Ecology and Society*, *26*(3), Article 24. https://doi.org/10.5751/ES-12579-260324

Timmermann, A., Damgaard, C., Strandberg, M. T., & Svenning, J.-C. (2015). Pervasive early 21st-century vegetation changes across Danish semi-natural ecosystems: more losers than winners and a shift towards competitive, tall-growing species. *Journal of Applied Ecology*, *52*(1), 21-30. https://doi.org/https://doi.org/10.1111/1365-2664.12374

Toivio, J., Helmisaari, H.-S., Palviainen, M., Lindeman, H., Ala-Ilomäki, J., Sirén, M., & Uusitalo, J. (2017). Impacts of timber forwarding on physical properties of forest soils in southern Finland. *Forest Ecology and Management*, *405*, 22-30. https://doi.org/10.1016/j.foreco.2017.09.022

Tölle, M. H., Gutjahr, O., Busch, G., & Thiele, J. C. (2014). Increasing bioenergy production on arable land: Does the regional and local climate respond? Germany as a case study [Article]. *Journal of Geophysical Research*, *119*(6), 2711-2724. https://doi.org/10.1002/2013JD020877

Tomao, A., Quatrini, V., Corona, P., Ferrara, A., Lafortezza, R., & Salvati, L. (2017). Resilient landscapes in Mediterranean urban areas: Understanding factors influencing forest trends. *Environ Res*, *156*, 1-9. https://doi.org/10.1016/j.envres.2017.03.006

Tomaz, A., Palma, P., Fialho, S., Lima, A., Alvarenga, P., Potes, M., Costa, M. J., & Salgado, R. (2020). Risk assessment of irrigation-related soil salinization and sodification in mediterranean areas [Article]. *Water (Switzerland)*, *12*(12), Article 3569. https://doi.org/10.3390/w12123569

Tóth, Z., Dombos, M., & Hornung, E. (2023). Urban soil quality deteriorates even with low heavy metal levels: An arthropod-based multi-indices approach [Article]. *Ecological Applications*, *33*(4), Article e2848. https://doi.org/10.1002/eap.2848

Tóth, Z., Hornung, E., & Szlavecz, K. (2021). Urban effects on saprophagous macroarthropods are mainly driven by climate: A global meta-analysis. *Science of The Total Environment*, *797*, 149182. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.149182

Tuomi, M., Rasinmäki, J., Repo, A., Vanhala, P., & Liski, J. (2011). Soil carbon model Yasso07 graphical user interface. *Environmental Modelling & Software*, *26*(11), 1358-1362. https://doi.org/https://doi.org/10.1016/j.envsoft.2011.05.009

Ťupek, B., Lehtonen, A., Mäkipää, R., Peltonen-Sainio, P., Huuskonen, S., Palosuo, T., Heikkinen, J., & Regina, K. (2021). Extensification and afforestation of cultivated mineral soil for climate change mitigation in Finland [Article]. *Forest Ecology and Management*, *501*, Article 119672. https://doi.org/10.1016/j.foreco.2021.119672

Turck, A., Schloemer, L., & Terlau, W. (2023). Farmers are caught in Tri-Dilemma - Objectives and Challenges for Biodiversity in German Nature-Protected Areas [Article]. *International Journal on Food System Dynamics*, *14*(2), 237-250. https://doi.org/10.18461/ijfsd.v14i2.F8

Unc, A., Altdorff, D., Abakumov, E., Adl, S., Baldursson, S., Bechtold, M., Cattani, D. J., Firbank, L. G., Grand, S., Guðjónsdóttir, M., Kallenbach, C., Kedir, A. J., Li, P., McKenzie, D. B., Misra, D., Nagano, H., Neher, D. A., Niemi, J., Oelbermann, M., . . . Borchard, N. (2021). Expansion of Agriculture in Northern Cold-Climate Regions: A Cross-Sectoral Perspective on Opportunities and Challenges [Article]. *Frontiers in Sustainable Food Systems*, *5*, Article 663448. https://doi.org/10.3389/fsufs.2021.663448

UNDDD. (2010). *Background Information*. United Nations Decade for Deserts and the Fight Against Desertification Retrieved 29.05 from https://www.un.org/en/events/desertification_decade/background.shtml

van der Linden, E. C., Haarsma, R. J., & van der Schrier, G. (2019). Impact of climate model resolution on soil moisture projections in central-western Europe. *Hydrology and Earth System Sciences*, *23*(1), 191-206. https://doi.org/10.5194/hess-23-191-2019

van der Schalie, R., van der Vliet, M., Rodríguez-Fernández, N., Dorigo, W. A., Scanlon, T., Preimesberger, W., Madelon, R., & de Jeu, R. A. M. (2021). L-Band Soil Moisture Retrievals Using Microwave Based Temperature and Filtering. Towards Model-Independent Climate Data Records. *Remote Sensing*, *13*(13).

Vanino, S., Nino, P., De Michele, C., Falanga Bolognesi, S., D'Urso, G., Di Bene, C., Pennelli, B., Vuolo, F., Farina, R., Pulighe, G., & Napoli, R. (2018). Capability of Sentinel-2 data for estimating maximum evapotranspiration and irrigation requirements for tomato crop in Central Italy [Article]. *Remote Sensing of Environment*, *215*, 452-470. https://doi.org/10.1016/j.rse.2018.06.035

Vanmaercke, M., Poesen, J., Maetens, W., de Vente, J., & Verstraeten, G. (2011). Sediment yield as a desertification risk indicator. *Science of The Total Environment*, *409*(9), 1715-1725. https://doi.org/https://doi.org/10.1016/j.scitotenv.2011.01.034

Vargas-Amelin, E., & Pindado, P. (2014). The challenge of climate change in Spain: Water resources, agriculture and land [Article]. *Journal of Hydrology*, *518*(PB), 243-249. https://doi.org/10.1016/j.jhydrol.2013.11.035

Vasenev, V. I., Smagin, A. V., Ananyeva, N. D., Ivashchenko, K. V., Gavrilenko, E. G., Prokofeva, T. V., Patlseva, A., Stoorvogel, J. J., Gosse, D. D., & Valentini, R. (2017). Urban Soil's Functions: Monitoring, Assessment, and Management. In A. Rakshit, P. C. Abhilash, H. B. Singh, & S. Ghosh (Eds.), *Adaptive Soil Management : From Theory to Practices* (pp. 359-409). Springer Singapore. https://doi.org/10.1007/978-981-10-3638-5_18

Vasileiadis, S., Puglisi, E., Arena, M., Cappa, F., van Veen, J. A., Cocconcelli, P. S., & Trevisan, M. (2013). Soil microbial diversity patterns of a lowland spring environment. *FEMS Microbiol Ecol*, *86*(2), 172-184. https://doi.org/10.1111/1574-6941.12150

Vázquez, E., Benito, M., Espejo, R., & Teutscherova, N. (2020). Response of soil properties and microbial indicators to land use change in an acid soil under Mediterranean conditions. *Catena*, *189*, 104486. https://doi.org/https://doi.org/10.1016/j.catena.2020.104486

Veerman, C., Correia, T. P., Bastioli, C., Biro, B., Bouma, J., Cienciala, E., Emmett, B., Frison, E. A., Grand, A., Filchew, L. H., Kriaučiūnienė, Z., Pogrzeba, M., Soussana, J.-F., Olmo, C. V., & Wittkowski, R. (2020). *Caring for soil is caring for life : ensure 75% of soils are healthy by 2030 for food, people, nature and climate : report of the Mission board for Soil health and food*.

Verburg, P. H., Koomen, E., Hilferink, M., Pérez-Soba, M., & Lesschen, J. P. (2012). An assessment of the impact of climate adaptation measures to reduce flood risk on ecosystem services. *Landscape Ecology*, *27*(4), 473-486. https://doi.org/10.1007/s10980-012-9715-6

Vicente-Vicente, J. L., Gómez-Muñoz, B., Hinojosa-Centeno, M. B., Smith, P., & Garcia-Ruiz, R. (2017). Carbon saturation and assessment of soil organic carbon fractions in Mediterranean rainfed olive orchards under plant cover management [Article]. *Agriculture, Ecosystems and Environment*, *245*, 135-146. https://doi.org/10.1016/j.agee.2017.05.020

Vidal, J. P., Martin, E., Kitova, N., Najac, J., & Soubeyroux, J. M. (2012). Evolution of spatio-temporal drought characteristics: Validation, projections and effect of adaptation scenarios [Article]. *Hydrology and Earth System Sciences*, *16*(8), 2935-2955. https://doi.org/10.5194/hess-16-2935-2012

Viedma, O., Moity, N., & Moreno, J. M. (2015). Changes in landscape fire-hazard during the second half of the 20th century: Agriculture abandonment and the changing role of driving factors [Article]. *Agriculture, Ecosystems and Environment*, *207*, 126-140. https://doi.org/10.1016/j.agee.2015.04.011

Virto, I., Imaz, M. J., Fernández-Ugalde, O., Gartzia-Bengoetxea, N., Enrique, A., & Bescansa, P. (2015). Soil degradation and soil quality in Western Europe: Current situation and future perspectives [Review]. *Sustainability (Switzerland)*, *7*(1), 313-365. https://doi.org/10.3390/su7010313

Waldhardt, R., Bach, M., Borresch, R., Breuer, L., Diekötter, T., Frede, H. G., Gäth, S., Ginzler, O., Gottschalk, T., Julich, S., Krumpholz, M., Kuhlmann, F., Otte, A., Reger, B., Reiher, W., Schmitz, K., Schmitz, P. M., Sheridan, P., Simmering, D., . . . Zörner, D. (2010). Evaluating today's landscape multifunctionality and providing an alternative future: A normative scenario approach [Article]. *Ecology and Society*, *15*(3). https://doi.org/10.5751/ES-03590-150330

Waldner, P., Marchetto, A., Thimonier, A., Schmitt, M., Rogora, M., Granke, O., Mues, V., Hansen, K., Pihl Karlsson, G., Žlindra, D., Clarke, N., Verstraeten, A., Lazdins, A., Schimming, C., Iacoban, C., Lindroos, A.-J., Vanguelova, E., Benham, S., Meesenburg, H., . . . Lorenz, M. (2014). Detection of temporal trends in atmospheric deposition of inorganic nitrogen and sulphate to forests in Europe. *Atmospheric Environment*, *95*, 363-374. https://doi.org/https://doi.org/10.1016/j.atmosenv.2014.06.054

Warner, D. J., Tzilivakis, J., Green, A., & Lewis, K. A. (2016). Rural Development Program measures on cultivated land in Europe to mitigate greenhouse gas emissions–regional “hotspots” and priority measures [Article]. *Carbon Management*, *7*(3-4), 205-219. https://doi.org/10.1080/17583004.2016.1214516

Webb, J., Rubio, J. L., & Fullen, M. (2018). Soil quality and policy. In S. M. Charlesworth & C. A. Booth (Eds.), *Urban Pollution: Science and Management* (pp. 57-68). Wiley-Blackwell.

Weigelt, J., Müller, A., Janetschek, H., & Töpfer, K. (2015). Land and soil governance towards a transformational post-2015 Development Agenda: an overview. *Current Opinion in Environmental Sustainability*, *15*, 57-65. https://doi.org/https://doi.org/10.1016/j.cosust.2015.08.005

Weiss, G., Lawrence, A., Hujala, T., Lidestav, G., Nichiforel, L., Nybakk, E., Quiroga, S., Sarvašová, Z., Suarez, C., & Živojinović, I. (2019). Forest ownership changes in Europe: State of knowledge and conceptual foundations. *Forest Policy and Economics*, *99*, 9-20. https://doi.org/10.1016/j.forpol.2018.03.003

Weiss, M., Jacob, F., & Duveiller, G. (2020). Remote sensing for agricultural applications: A meta-review [Article]. *Remote Sensing of Environment*, *236*, Article 111402. https://doi.org/10.1016/j.rse.2019.111402

Wellmitz, J., Bandow, N., & Koschorreck, J. (2023). Long-term trend data for PFAS in soils from German ecosystems, including TOP assay. *Sci Total Environ*, *893*, 164586. https://doi.org/10.1016/j.scitotenv.2023.164586

Wong, J. K. H., Lee, K. K., Tang, K. H. D., & Yap, P. S. (2020). Microplastics in the freshwater and terrestrial environments: Prevalence, fates, impacts and sustainable solutions [Review]. *Science of The Total Environment*, *719*, Article 137512. https://doi.org/10.1016/j.scitotenv.2020.137512

Wunder, S., & Bodle, R. (2019). Achieving land degradation neutrality in Germany: Implementation process and design of a land use change based indicator. *Environmental Science & Policy*, *92*, 46-55. https://doi.org/https://doi.org/10.1016/j.envsci.2018.09.022

Yang, B., Banerjee, S., Herzog, C., Ramírez, A. C., Dahlin, P., & van der Heijden, M. G. A. (2021). Impact of land use type and organic farming on the abundance, diversity, community composition and functional properties of soil nematode communities in vegetable farming [Article]. *Agriculture, Ecosystems and Environment*, *318*, Article 107488. https://doi.org/10.1016/j.agee.2021.107488

Yigini, Y., & Panagos, P. (2016). Assessment of soil organic carbon stocks under future climate and land cover changes in Europe. *Science of The Total Environment*, *557-558*, 838-850. https://doi.org/https://doi.org/10.1016/j.scitotenv.2016.03.085

Yin, R., Eisenhauer, N., Schmidt, A., Gruss, I., Purahong, W., Siebert, J., & Schädler, M. (2019). Climate change does not alter land-use effects on soil fauna communities. *Applied Soil Ecology*, *140*, 1-10. https://doi.org/https://doi.org/10.1016/j.apsoil.2019.03.026

Yumashev, D., Janes-Bassett, V., Redhead, J. W., Rowe, E. C., & Davies, J. (2022). Terrestrial carbon sequestration under future climate, nutrient and land use change and management scenarios: a national-scale UK case study. *Environmental Research Letters*, *17*(11), 114054. https://doi.org/10.1088/1748-9326/aca037

Zander, P., Amjath-Babu, T. S., Preissel, S., Reckling, M., Bues, A., Schläfke, N., Kuhlman, T., Bachinger, J., Uthes, S., Stoddard, F., Murphy-Bokern, D., & Watson, C. (2016). Grain legume decline and potential recovery in European agriculture: a review [Review]. *Agronomy for Sustainable Development*, *36*(2), Article 26. https://doi.org/10.1007/s13593-016-0365-y

Zapata-Sierra, A. J., Zapata-Castillo, L., & Manzano-Agugliaro, F. (2022). Water resources availability in southern Europe at the basin scale in response to climate change scenarios [Article]. *Environmental Sciences Europe*, *34*(1), Article 75. https://doi.org/10.1186/s12302-022-00649-5

Zegada-Lizarazu, W., & Monti, A. (2011). Energy crops in rotation. A review [Review]. *Biomass and Bioenergy*, *35*(1), 12-25. https://doi.org/10.1016/j.biombioe.2010.08.001

Zhou, J., Briciu-Burghina, C., Regan, F., & Ali, M. I. (2023). A Data-Driven Approach for Building the Profile of Water Storage Capacity of Soils. *Sensors*, *23*(12).

Zistl-Schlingmann, M., Kwatcho Kengdo, S., Kiese, R., & Dannenmann, M. (2020). Management Intensity Controls Nitrogen-Use-Efficiency and Flows in Grasslands—A 15N Tracing Experiment. *Agronomy*, *10*(4).

Žížala, D., Zádorová, T., & Kapička, J. (2017). Assessment of soil degradation by erosion based on analysis of soil properties using aerial hyperspectral images and ancillary data, Czech Republic [Article]. *Remote Sensing*, *9*(1), Article 28. https://doi.org/10.3390/rs9010028

Zornoza, R., Acosta, J. A., Bastida, F., Domínguez, S. G., Toledo, D. M., & Faz, A. (2015). Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health [Article]. *SOIL*, *1*(1), 173-185. https://doi.org/10.5194/soil-1-173-2015

Zwetsloot, M. J., van Leeuwen, J., Hemerik, L., Martens, H., Simó Josa, I., Van de Broek, M., Debeljak, M., Rutgers, M., Sandén, T., Wall, D. P., Jones, A., & Creamer, R. E. (2021). Soil multifunctionality: Synergies and trade-offs across European climatic zones and land uses [Article]. *European Journal of Soil Science*, *72*(4), 1640-1654. https://doi.org/10.1111/ejss.13051

Appendix

1. **Milestone M1 – Protocol for the analysis of the drivers for soil health – Methodology**

2. **Preliminary list of drivers communicated with the Think Tanks in October 2023**

3. **Position statement: BonaRes Repository as trusted repository in accordance with Horizon Europe criteria**

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