Soils
SOLO for
Europe

Typology of Drivers of Soil Health across European Union

Deliverable 3.1

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

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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 soil 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 led 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.

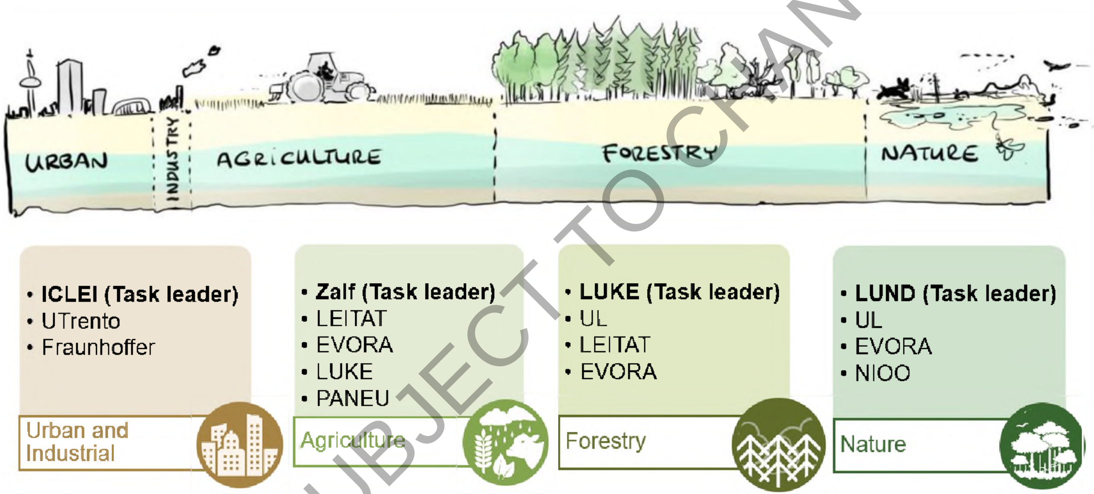

Figure 1 : Top. – Conceptualization of the land use types (Drawings: Joost Fluitsma, sourced from SMS ontology report (https://www.soilmissionsupport.eu/news-2022/ontology), Bottom – Land use sub-types, adjusted with PREPSOIL land use categorisation.

Section 2.2 elaborates the protocol adopted to carry out the steps. The protocol was developed and outlined in detail as a milestone M1 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 the EU and it is represented graphically in the Figure 2. In that regard, 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 be 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.

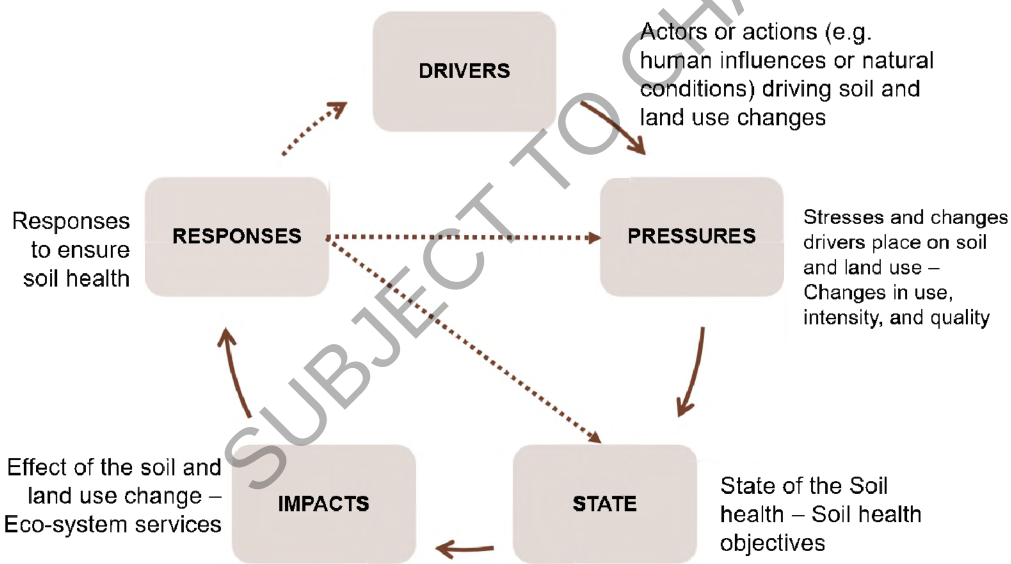

Figure 2 : DPSIR Framework schematic for future soil and land use management for soil health (adapted from EEA (1999))

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, the aging of rural populations 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 • Earthquakes	• 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.

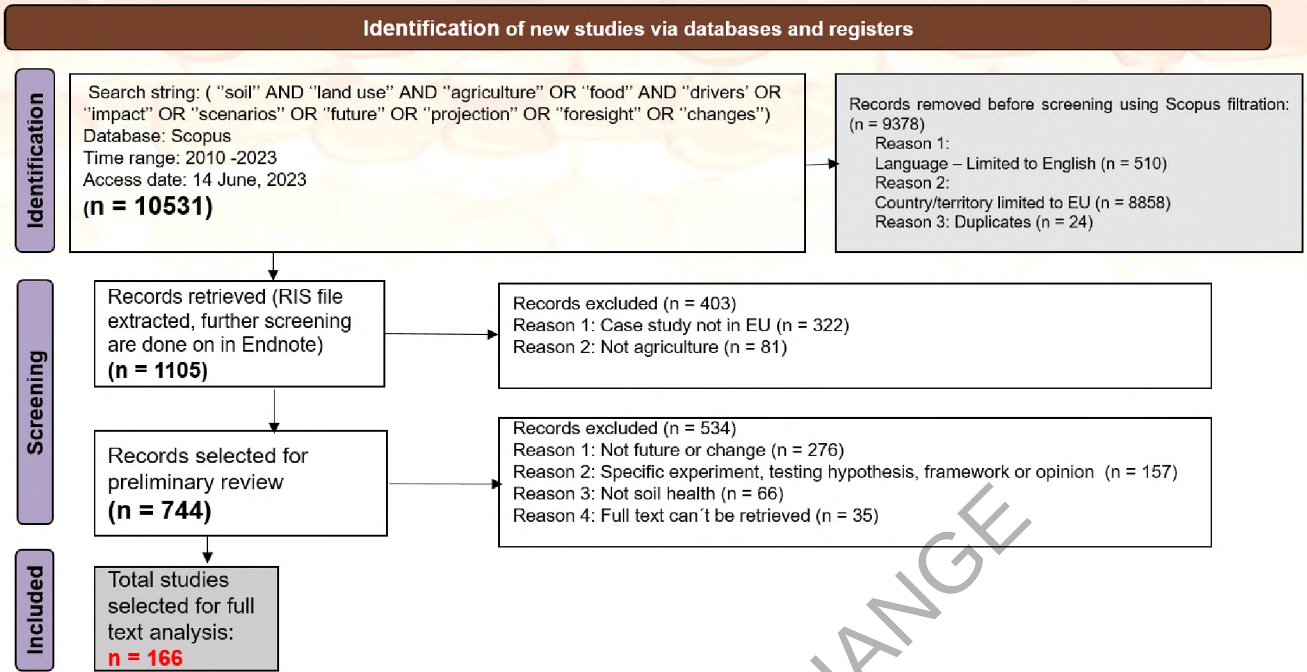

Figure 3: PRISMA flow diagram for literature review for Agriculture land use

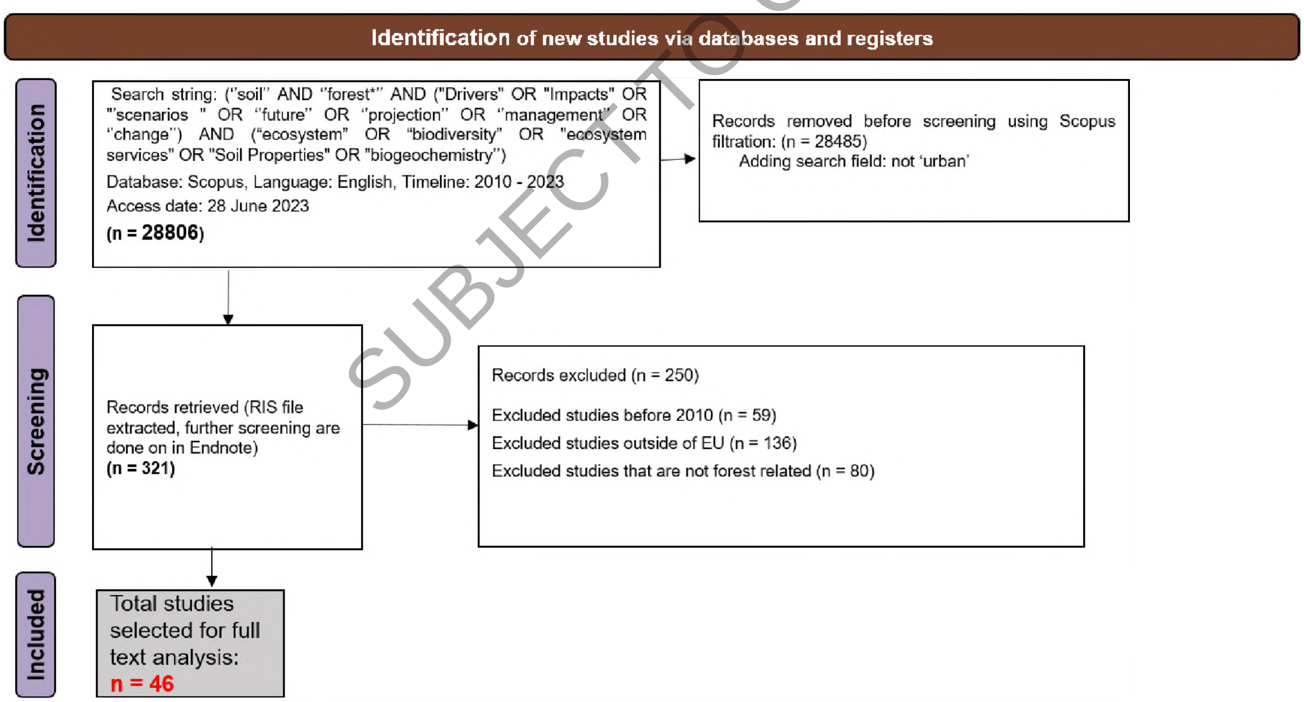

Figure 4: PRISMA flow diagram for literature review for Forest land use

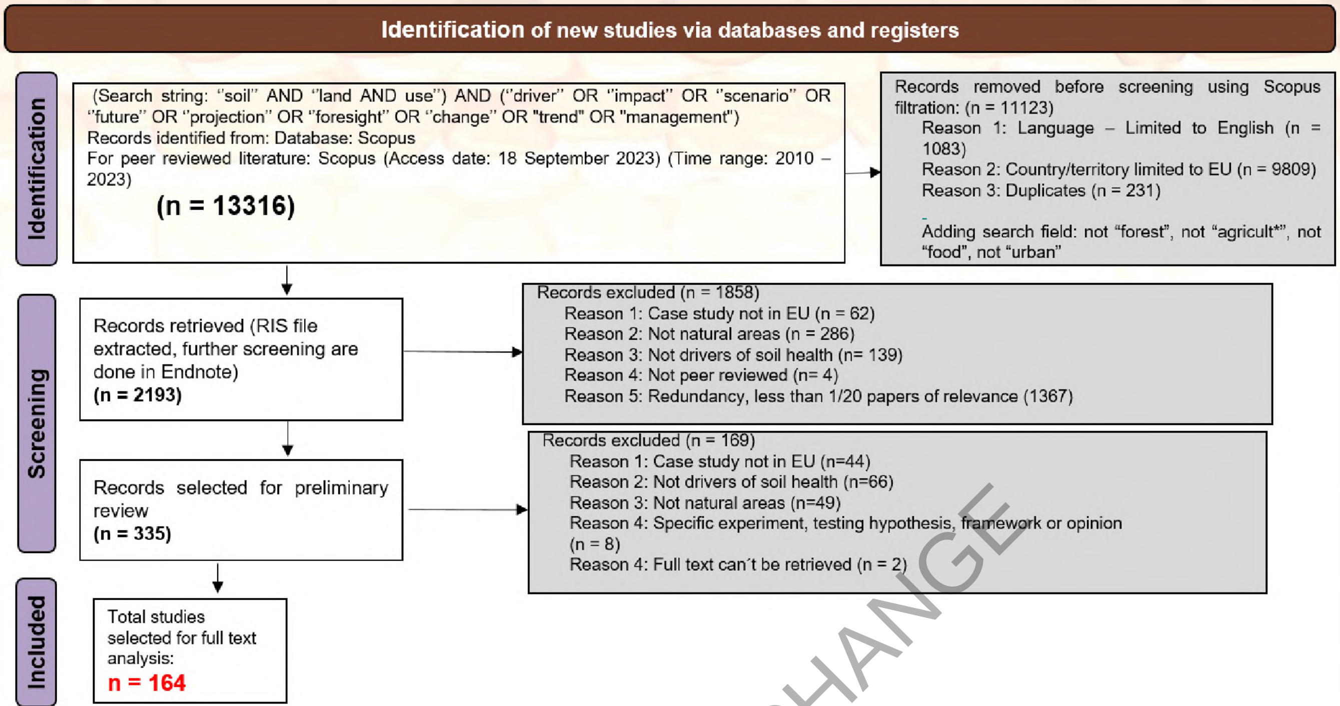

Figure 5: PRISMA flow diagram for literature review for Nature land use

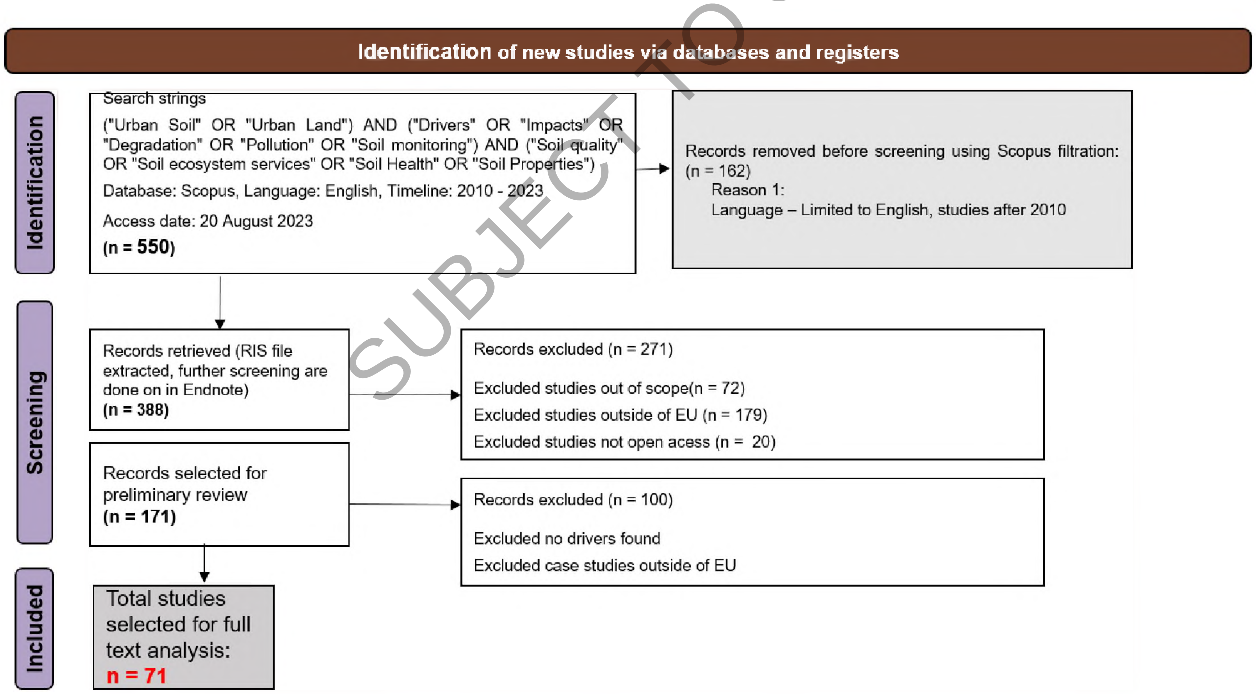

Figure 6: PRISMA flow diagram for literature review for Urban and industrial land use

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	(Brangari 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 its 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.

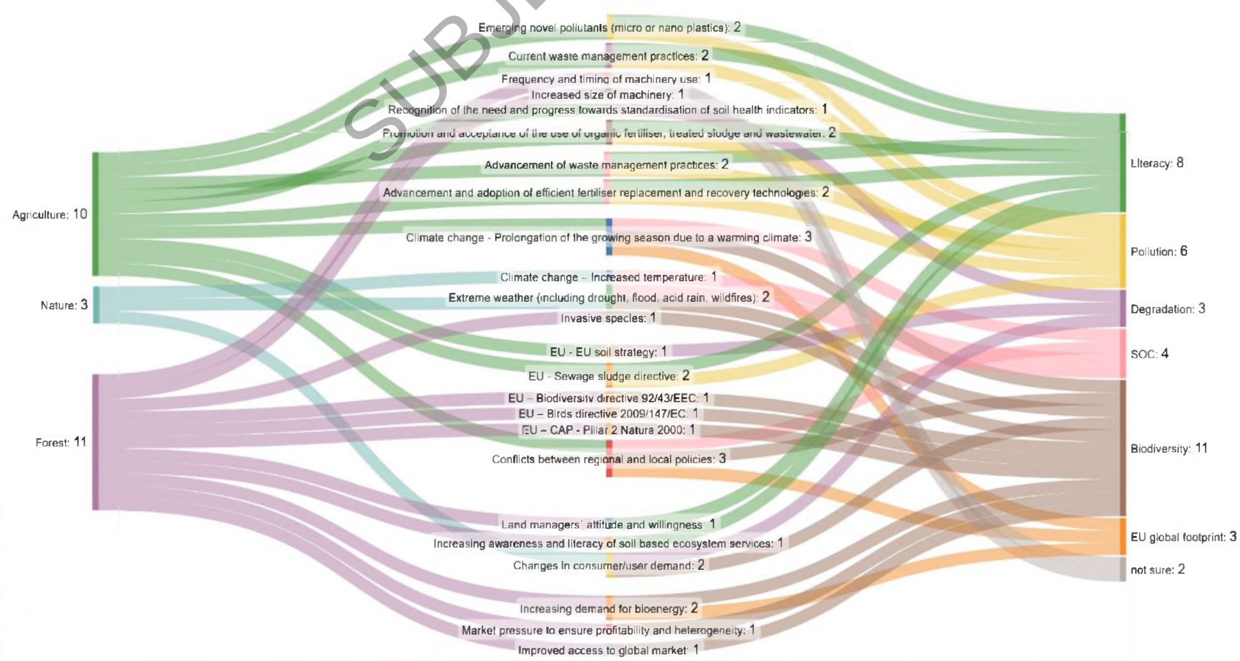

Figure 7: Drivers for soil health in Sweden

The easiest and the earliest sorting of the drivers is by land use. Figure 8 presents the general outcome of that approach. 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).

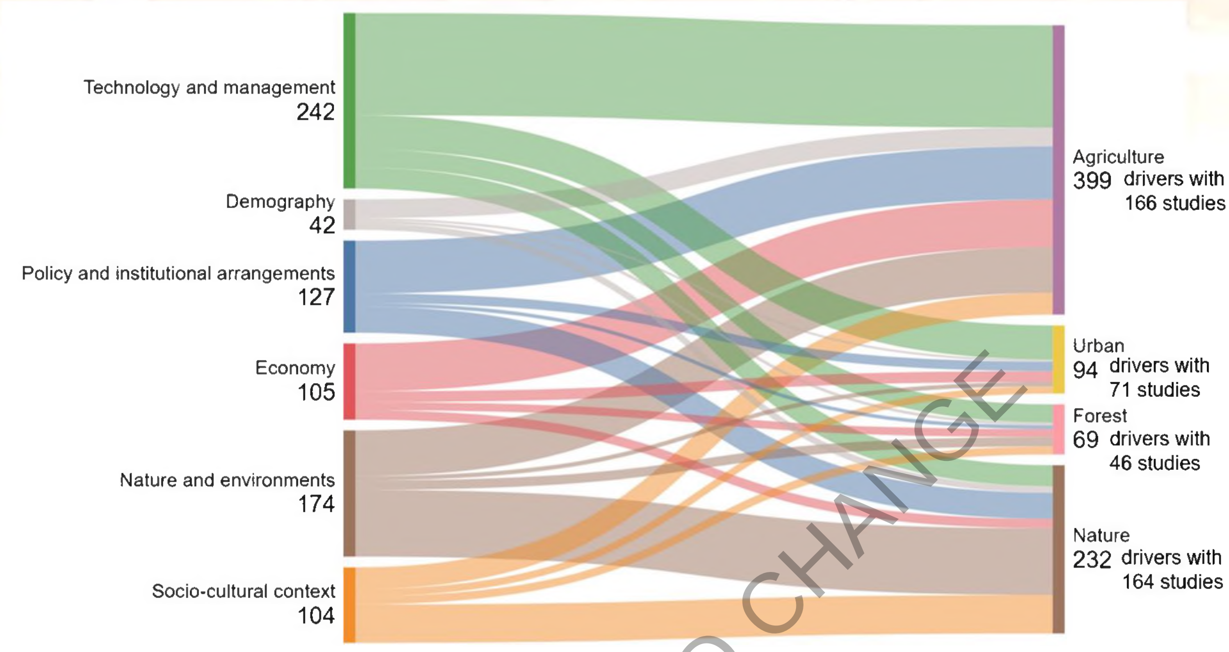

Figure 8: Numbers of drivers identified according to land uses.

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 regard 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.

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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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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**

Appendix 1

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SOLO

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).

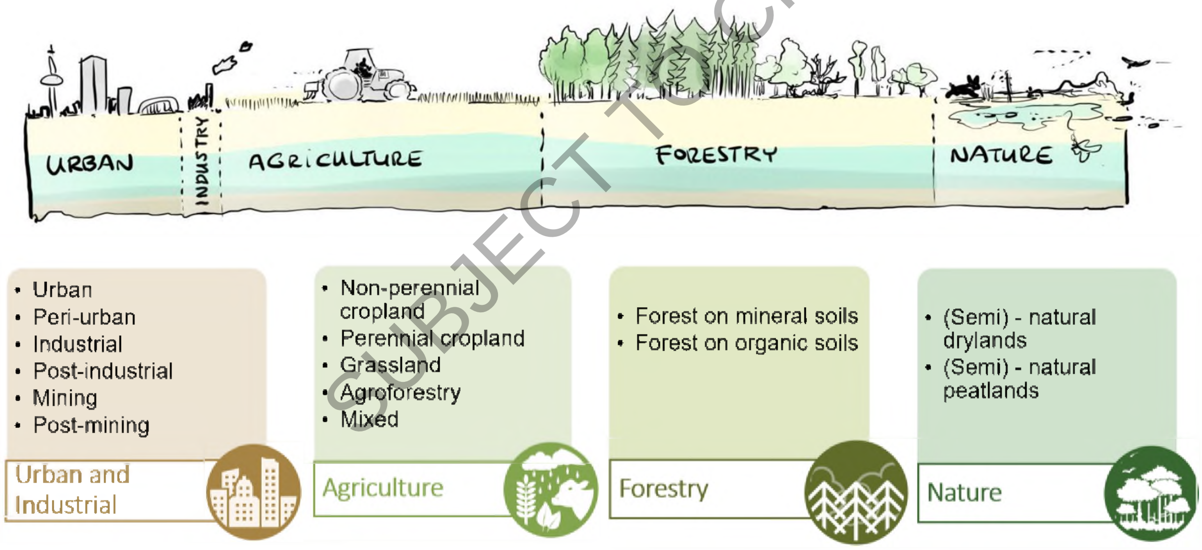


Figure 1 : Top. – Conceptualization of the land-use types. The length of the box is indicative for the percentage that that land-use covers Europe. All lengths added equals 100% (Drawings: Joost Fluitsma, sourced from SMS ontology report (https://www.soilmissionsupport.eu/news-2022/ontology), Bottom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

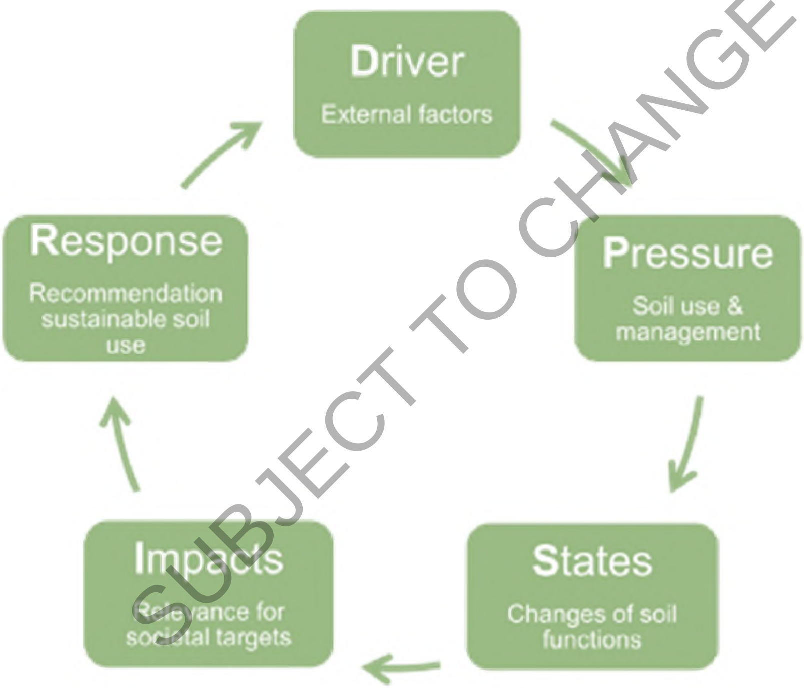


Figure 2: DPSIR Framework schematic for future soil and land use management (edited from Gabrielsen & Bosch (2003))

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.

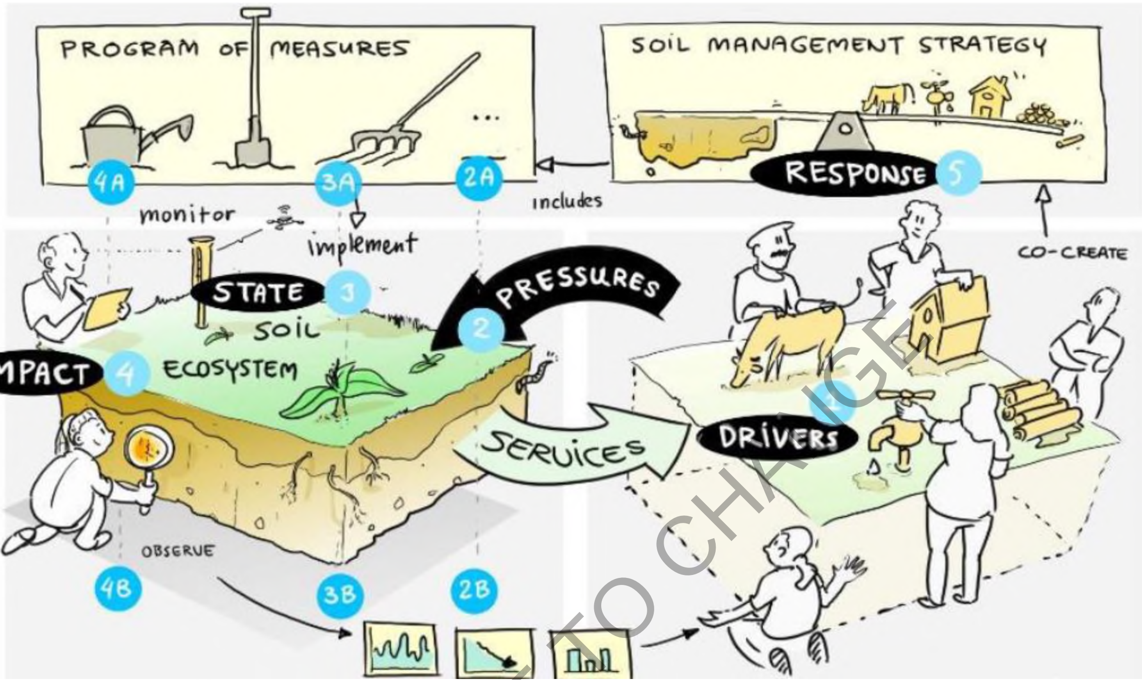


Figure 3: The DPSIR framework superimposed on the conceptual model for soil management (Drawings: Joost Fluitsma, sourced from SMS ontology report (https://www.soilmissionsupport.eu/news-2022/ontology))

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

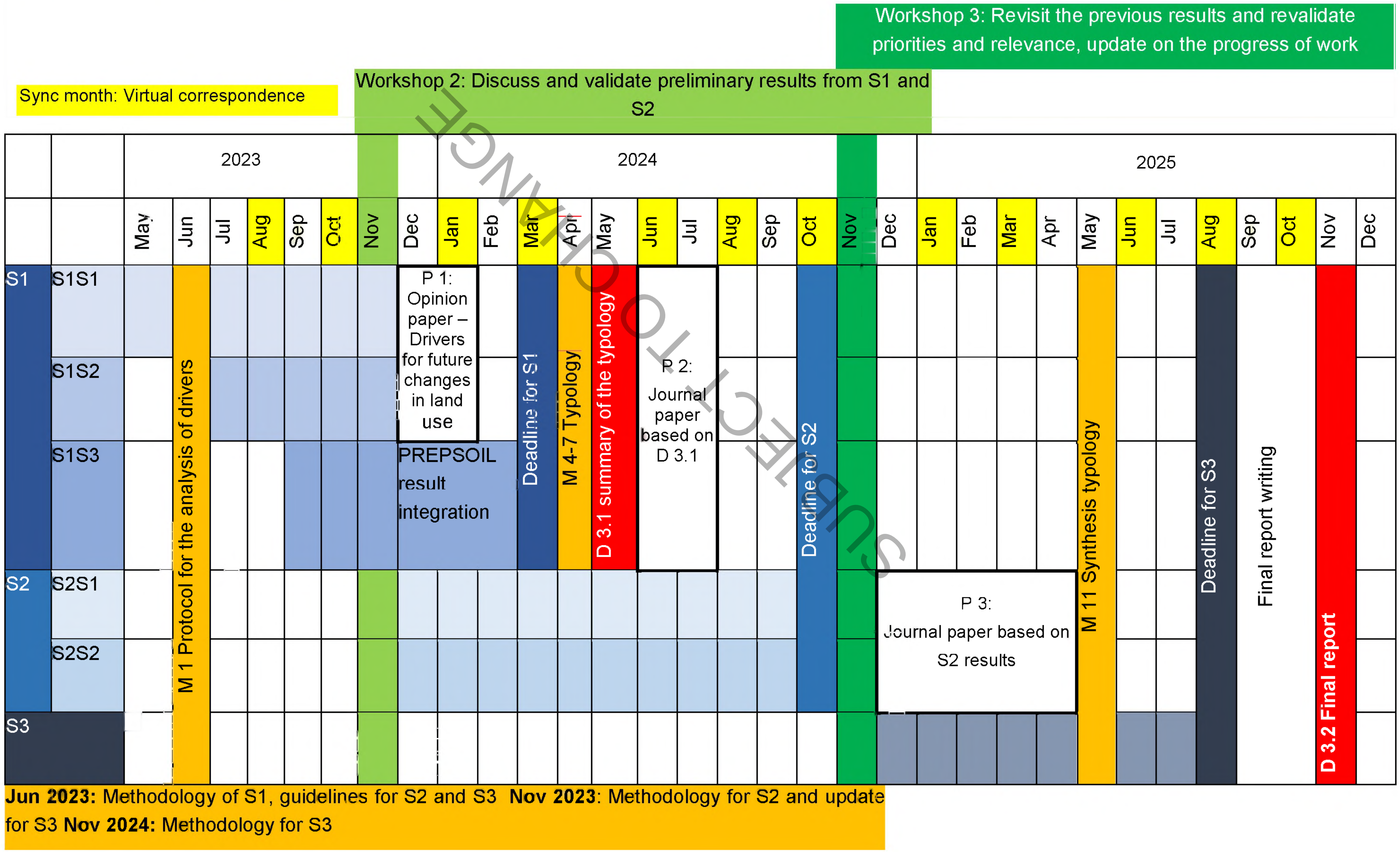
- Step 2 (S2) - Drivers interactions and impacts on the soil and land use management over time
  - Sub-step 1 (S2.1) – Fixed scenario with EU climate targets - Timeline complying with the EU policy goals and climate targets and EU green deal targets 2030/2050
  - Sub-step 2 (S2.2) – Flexible scenario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



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 CO_2 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).

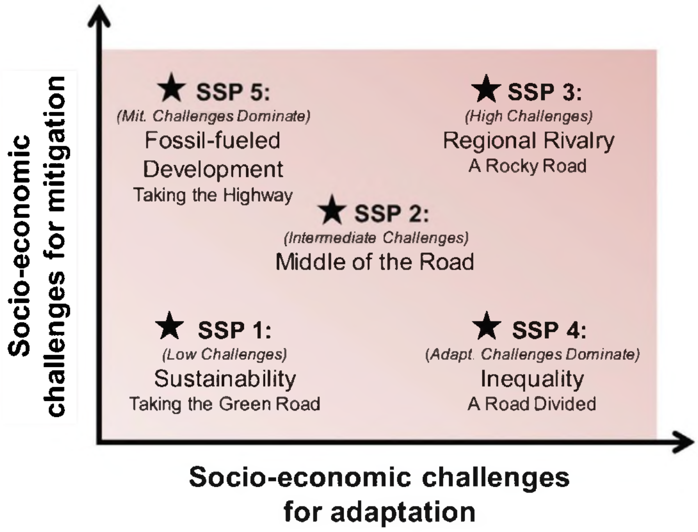


Figure 4 : The Eur-Agri SSPs (source : O'Neill et al. (2017))

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.

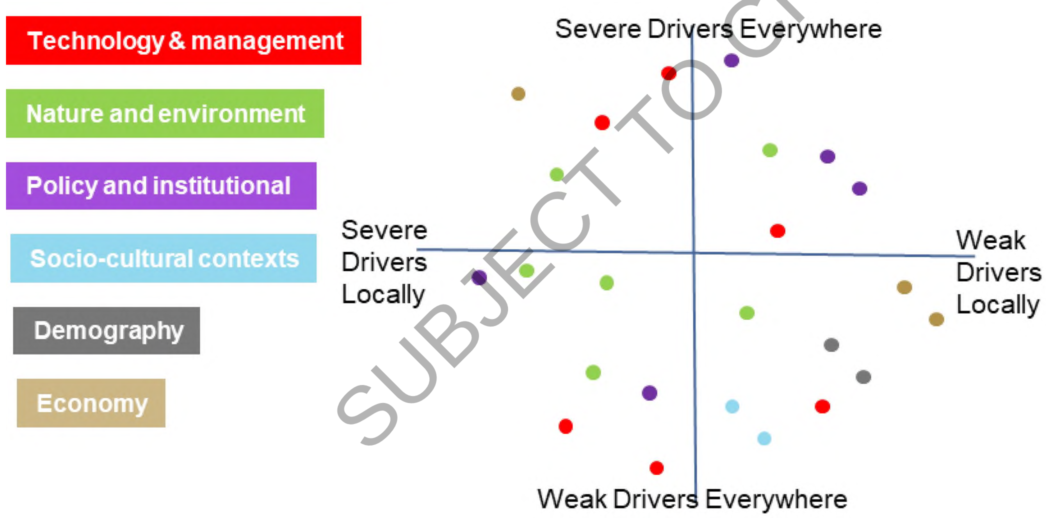


Figure 5: Example foresight of emerging soil health drivers

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8 Appendix

8.1 Literature list

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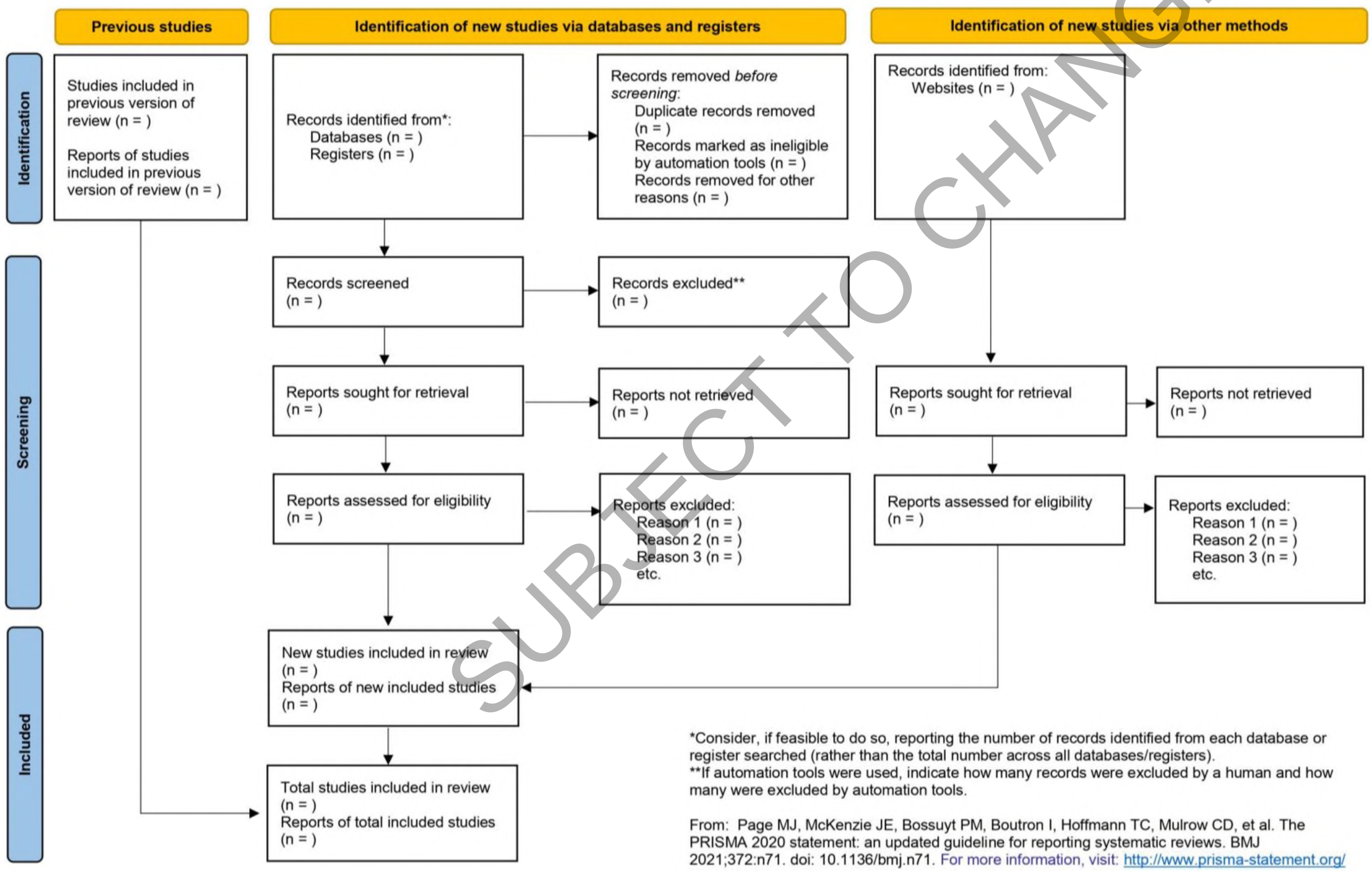
8.2 PRISMA protocol

(The editable doc file is shared separately)

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



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

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Footprints on soil

This document provides an early mapping important drivers for soil health objective 'EU global footprint on soils´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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 task of WP3 is separated across four land uses (agriculture, forest, urban and industrial areas, and natural areas) lead by four task leaders. As per the protocol of the WP3 (link), the ongoing work of WP3 is the creation of an inventory of drivers of changes for different land-uses through a scoping literature review. 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 (e.g. from agriculture to forest, from grassland to urban, use to abandonment)
- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

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Note: Please do not circulate or cite.

[1] https://www.eea.europa.eu/publications/TEC25
[2] https://www.bonares.de/socioeconomics/assessment/background-knowledge/dpsir
[3] https://www.soilmissionsupport.eu/news-2022/ontology
[4] https://resoilfoundation.org/wp-content/uploads/2023/06/1.PREPSOIL_Overview-and-WP2_RIMINI_PG_04.05.23.pdf
[5] https://doi.org/10.1136/bmj.n71

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Footprints on soil

Table: List of preliminary drivers (excerpts from the ongoing list of drivers results of literature review), the highlighted drivers are not specific to any soil health objectives. For 'likely to affect' columns, empty cell represents no change, '?' represents unsure/potential change, 'X' represents sure/obvious change.

Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Changes in food habits, changing human diet (leading to average land use savings of shifting from current human diet to national recommended diet is 3.32m2/person/day) (decreased footprint)	Relevant everywhere	x	x	x
Shift in dietary preferences (leading to increased food import) (increased global footprint)	Relevant everywhere	x	x	?
Urban land take/ sprawl (fuelled by e.g tourism, residence/second residence, associated infrastructure)(increased footprint)	Relevant everywhere (Specific Athens (Greece), Spain)	x	x	x
Reuse of food waste (as feedstocks leading to less land, the land requirement of EU pork production could decrease by more than 20% compared with today's land-use.)(decreased footprint)	Relevant everywhere	x	x	x
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	x
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	x
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	x	x	x
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranea n	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize	Germany (Elbe river basin)	x	?	x

cultivation in suitable land) (unsure soil health objective impact)				
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		x	x
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		x	x
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x

Forestry

Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?

Nature

Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
None detected so far				

Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Need for sustainable soil management practices to mitigate climate change impacts	Relevant everywhere (Green urban areas)		x	
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategy	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Land degradation

This document provides an early mapping important drivers for soil health objective 'land degradation´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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.

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[4] https://resoilfoundation.org/wp-content/uploads/2023/06/1.PREPSOIL_Overview-and-WP2_RIMINI_PG_04.05.23.pdf
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Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Climate change impacts (leading to degradation, esertification and possibly erosion in drylands)	Relevant everywhere (drylands)	?	?	?
Climate change (leading to degradation, desertification and possibly erosion)	Southern Europe	?	?	?
Soil salinization due to introduction of irrigation (Soil degradation trend)	Mediterranean	?	?	?
Soil acidification (Soil degradation trend)	Western Europe (EU17 possibly)	?	?	?
High salinity and low precipitation (leading to land abandonment)	Spain (Semi-arid region)	x	x	x
Increases relevance of 'green' energy policies in industrialised countries for drylands, e.g. biofuel production (leading to desertification and possibly erosion in drylands)	Relevant everywhere (drylands)	?	?	?
National level obstacle for adapting regional policies (Peatland drainage for agriculture)	Relevant everywhere (Peatlands)	?	?	?
Inadequate and inefficient economic incentives via policy measures (CAP Peatland drainage for agriculture)	Relevant everywhere (Peatlands)	?	?	?
Population density (decreasing, can bring indirect positive changes)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (leading to intensification)	Relevant everywhere	?	x	x
Changes in consumption pattern and demand (leading to desertification and possibly erosion)in drylands)	Relevant everywhere (drylands)	?	?	?
Limited attention of European farmers to other soil functions apart from primary production	Relevant everywhere		?	?
Rising food and energy prices (leading to desertification and possibly erosion in drylands)	Relevant everywhere (drylands)	x	x	x
Emerging carbon markets (leading to desertification and possibly erosion in drylands)	Relevant everywhere (drylands)	x	x	x
Warfare activities in relation to land degradation	Past and present active war zone	x	x	x
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	x
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	x
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	x	x	x

Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		x	x
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable	Relevant everywhere (field experiments across EU)		x	x

intensification) (potential increase in soil nutrients with increased production)				
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x
Forestry				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Existing and increasing recreational values of forests	Relevant everywhere	?	?	?
Acid rain (leading to acidification)	Relevant everywhere	x	x	x
Salinization				
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?
Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Current management (leading to pollution/eutrophication)	Relevant everywhere (Moors and heathland)	X	X	X
Land degradation risk mitigation strategies	Relevant everywhere	x	x	x
Climate change - increased/decreased rainfall (increased/decreased soil erosion)	Relevant everywhere	?		
Climate change- increased temperature (leading to afforestation or cultivation of moors and heathland)	Relevant everywhere (Moors and heathland)	x	x	x
Climate change- increased temperature and increased/decreased precipitation (leading to degradation of managed or natural grassland)	Relevant everywhere (grassland)	?	?	
Climate change - temperature/rainfall (increased land degradation, desertification)	Italy	?	?	
Demand change - economic and population growth (increased desertification)	Italy	?	?	
Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Waste management: Domestic sources of pollution	Relevant everywhere (dump sites)			x
Urbanisation and infrastructure construction (industrial, commercial, residential, transport etc.)	Relevant everywhere	x	x	
Parent materials for urban soil formation	Relevant everywhere			x
Growing population density in urban areas	Relevant everywhere	x	x	
Changes in land use patterns and increasing demand for industrial areas	Relevant everywhere	x	x	
Application of circular economy principles for the recycling or reuse of excavated soil	Relevant everywhere			x

	(Constructionsi tes)			
Growing concerns about soil degradation and erosion in industrial and urban areas	Relevant everywhere	x		
Increasing groundwater abstractions as a result of concurrent residential and agricultural land/water uses	Relevant everywhere		x	x
Invasive alien species	Relevant everywhere		x	x
War	Relevant everywhere	x	x	x
Promote land reuse in urban areas	Relevant everywhere	x	x	
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategyf	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil biodiversity

This document provides an early mapping important drivers for soil health objective 'soil stricture (soil biodiversity)´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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 task of WP3 is separated across four land uses (agriculture, forest, urban and industrial areas, and natural areas) lead by four task leaders. As per the protocol of the WP3 (link), the ongoing work of WP3 is the creation of an inventory of drivers of changes for different land-uses through a scoping literature review. 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 (e.g. from agriculture to forest, from grassland to urban, use to abandonment)
- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

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Table: List of preliminary drivers (excerpts from the ongoing list of drivers results of literature review), the highlighted drivers are not specific to any soil health objectives. For 'likely to affect' columns, empty cell represents no change, '?' represents unsure/potential change, 'X' represents sure/obvious change.

Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Potential policy and trade reforms (removal of Pillar 1 support payments and trade liberalisation leading to reduced farmland biodiversity)	Germany		x	x
Environmental Policy (Land use policy change leading to protection of soil and environmental biodiversity and ecosystem)	Portugal (Centro and Alentejo regions)	x	x	x
Agri-environmental policy and Natura 2000 (Land use policy change leading to protection of soil and environmental biodiversity and ecosystem)	Portugal (Centro and Alentejo regions)		x	x
Afforestation under CAP investment (Land use policy change leading afforestation, protection of soil and environmental biodiversity and ecosystem)	Portugal (Centro and Alentejo regions)	x	x	x
Crop diversification and organic farming as part of CAP (have no impact on soil biodiversity)	Sweden		x	x
Intensive agriculture and management intensification due to increasing demands (leading to substantial reduction of soil biodiversity)	Italy (South Tyrole)		x	x
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	x
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	x
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	x	x	x
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranea n	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x

Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		x	x
Agri-environmental measures (AEM payments) (leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		x	x
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x
Forestry				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?

Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Current management (leading to pollution/eutrophication and possibly decreased soil biodiversity)	Relevant everywhere (Moors and heathland)	X	X	X
Climate change- increased temperature (leading to afforestation or cultivation of moors and heathland, reduced/impacted soil biodiversity)	Relevant everywhere (Moors and heathland)	X	X	X
Climate change - increased temperature and increased/decreased precipitation (land degradation, loss of soil biodiversity)	Relevant everywhere including agriculture and forest)	?	X	
Demand change - economic growth (impact to soil microbial community with increasing land use intensity)	Germany	?	?	?

Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Conservation of soil microbial communities through the implementation of ecosystem restoration practices and pollution reduction strategies	Relevant everywhere			x
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategy	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x

Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil erosion

This document provides an early mapping important drivers for soil health objective ´soil erosion´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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.

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- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

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Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Technological developments (machinery, enlargement of field size to help mechanisation) (leading to widening of hill terrace)(increased erosion)	Spain		X	X
Development and introduction of machinery (led to excessive heavy mechanization (unsustainable practice) (increased erosion)	Relevant everywhere (Hilly and mountainous region)		X	X
Climate change (leading to desertification and possibly erosion in drylands)	Relevant everywhere (drylands) (southern Europe)	X	X	X
Extreme weather conditions	Norway	X	X	X
Climate change - increased rainfall (water erosion)	(Arid and cold zones) (Hilly and mountainous region) (France Germany Northern Italy Belgium)	?	?	?
Climate change - increased rainfall (water erosion decrease)	Portugal, France, southern Italy, Greece, Bulgaria	?	?	?
Climate change - increased drought (wind erosion)	Limited areas of Spain, South Italy, Bulgaria, eastern Greece, and the Mediterranean coast in Provence	?	?	?
Climate change - both increased rainfall and increased drought (both water and wind erosion)	Some parts of the Mediterrian	?	?	?
Decrease in water resources	Central Spain		?	X
Climate change - Prolongation of the growing season due to a warming climate (erosion decrease due to cover crop)	Finland	X	?	X
GAEC (Good Agricultural and Environmental Conditions) as part of Common Agricultural Policies (CAP) reform in 2003	Italy	?	?	X
Common Agricultural Policy (CAP) and Good Agricultural Environmental Conditions (GAEC) requirement (Leading to adoption of Good agriculture practices such as conservation tillage etc.)	Relevant everywhere		?	X
Population increase and subsequent increase of global demand for food (leading to intensification)	Relevant everywhere	?	X	X
Decline in active labor in agriculture (demography change leading to abandonment of farmland, leading to overall decrease in erosion)	Centro and Alentejo regions, Portugal	X	X	X
Depopulation of rural areas (resulting in farm abandonment, erosion improved in arid region, worsened in semi-arid region)	Spain	X	X	X
Aging population (resulting in citrus farm abandonment, decrease in erosion)	Valencia, Spain	X	X	X
Changes in consumption pattern and demand (leading to desertification and possibly erosion)in drylands)	Relevant everywhere (drylands)	?	?	?

Farmers´ lack of willingness to adapt Sustainable practices and policy measures (i.e Nimby, unwillingness to adapt to cover crop for vineyards even though cost provided by government)	Central Spain		?	x
Lack of efficient communication of scientific knowledge regarding soil degradation (unwillingness to adapt to cover crop for vineyards even though cost provided by government)	Central Spain		?	x
Biofuel cropping in abandoned or unsuitable agricultural land (areas with natural constraints, ie, ANC land, decrease in erosion)	Relevant everywhere	x	x	?
Reduction of market price (resulting in citrus farm abandonment, decrease in erosion)	Valencia, Spain	x	x	x
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	x
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	x
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	x	x	x
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		x	x
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x

Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		x	x
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x

Forestry

Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Current site preparation practice (e.g. tillage) (boreal coniferous forest)	Boreal	x	x	x
Water management and drainage (impacting soil erosion)	Relevant everywhere	x	x	x
High wind events (potential increase resulting in soil erosion)	Relevant everywhere (except Boreal)	x	x	x
Current and increasing precipitation (increasing water erosion)	Relevant everywhere	?	?	?
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?

Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Climate change - rainfall erosivity (need for predictive tools)	Serbia (south)	X	X	
Climate change - incraesed/decreased rainfall erosivity (increased soil erosion)	Romania	?	?	?
Climate change - changes in rainfall intensity (increased soil erosion)	Switzerland	?	?	
Climate change - increased precipitation (increased soil erosion prevention)	Switzerland	?	?	
Climate change - increased/decreased rainfall (increased/decreased soil erosion)	Relevant everywhere (Europe)	?		
Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Promote the implementation of infrastructure for flood control and watershed restorations	Relevant everywhere			x
Implementation of techniques for the stabilization of slope zones and prevention of soil erosion	Relevant everywhere			x
High-intensity rainfall events	Relevant everywhere		x	x
Increase in high wind events	Relevant everywhere		x	x
Changes in precipitation patterns including amount, intensity and distribution	Relevant everywhere			x
Changes in wind direction, strength and intensity produced by climate change	Relevant everywhere			x
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategy	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x

Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

SOILS FOR EUROPE
SOLO Soil literacy

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil literacy

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- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

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Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Technological advances in the topographic survey (e.g. innovative remote sensing techniques such as drones and airborne laser scanning, improved knowledge)	Relevant everywhere (Hilly and mountainous region)		?	x
Farmers´ lack of willingness to adapt Sustainable practices and policy measures (i.e Nimby, unwillingness to adapt to cover crop for vineyards even though cost provided by government)	Central Spain		?	x
Lack of efficient communication of scientific knowledge regarding soil degradation (unwillingness to adapt to cover crop for vineyards even though cost provided by government)	Central Spain		?	x
Farmers´ attitude and willingness (rising demands among farmers for more local appreciation of their effort)	Germany	?	?	?
Demand behaviour and consumer preferences/structure of the population	Germany	?	?	?
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	x
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	x
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	x	x	x
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x

Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		x	x
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		x	x
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x
	Forestry			
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?

Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
None detected so far				
Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Increase in research and literacy on urban soil ecosystem services	Relevant everywhere	x	x	x
Development of guidelines and standards for sustainable land use planning and management	Relevant everywhere			x
National and regional policies promoting sustainable land use practices	Relevant everywhere		x	x
Incentives and regulations to encourage sustainable soil management in urban and industrial areas	Relevant everywhere			x
Collaboration between government agencies, research institutions, and industry stakeholders	Relevant everywhere (Green urban areas)			x
Awareness and concern among the public about soil health and its impacts on human health and food security	Relevant everywhere	?	?	?
Environmental education and citizen science	Relevant everywhere		x	x
Awareness rising and recognition	Relevant everywhere		x	x
Community engagement and participation in urban and industrial land use planning	Relevant everywhere (Green urban areas)	?	?	?
Cultural values and practices related to land and soil stewardship	Relevant everywhere (Continuous urban fabric)	?	?	?
Society and Local goverment´s value perception towards soil´s ecosystem services potential	Relevant everywhere	x	x	x
Development of sustainable and resilient industrial and urban areas to attract investments	Relevant everywhere (Continuous urban fabric)			x
Economic benefits of sustainable soil management practices in industrial and urban area	Relevant everywhere (Industrial or commercial area)			x
Potential for creating green jobs in soil health research, monitoring, and management	Relevant everywhere			x
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	

Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategyf	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil organic carbon stocks

This document provides an early mapping important drivers for soil health objective 'soil organic carbon stock´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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 task of WP3 is separated across four land uses (agriculture, forest, urban and industrial areas, and natural areas) lead by four task leaders. As per the protocol of the WP3 (link), the ongoing work of WP3 is the creation of an inventory of drivers of changes for different land-uses through a scoping literature review. 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 (e.g. from agriculture to forest, from grassland to urban, use to abandonment)
- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

For additional information, please contact Dr. Shaswati Chowdhury (shaswati.chowdhury@zalf.de) or Prof. Dr. Katharina Helming (helming@zalf.de).

Note: Please do not circulate or cite.

[1] https://www.eea.europa.eu/publications/TEC25
[2] https://www.bonares.de/socioeconomics/assessment/background-knowledge/dpsir
[3] https://www.soilmissionsupport.eu/news-2022/ontology
[4] https://resoilfoundation.org/wp-content/uploads/2023/06/1.PREPSOIL_Overview-and-WP2_RIMINI_PG_04.05.23.pdf
[5] https://doi.org/10.1136/bmj.n71

Table: List of preliminary drivers (excerpts from the ongoing list of drivers results of literature review), the highlighted drivers are not specific to any soil health objectives. For 'likely to affect' columns, empty cell represents no change, '?' represents unsure/potential change, 'X' represents sure/obvious change.

Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Climate change (leading to adaptation strategies including cropping pattern, residue management, conservation tillage such as no tillage and reduced tillage)(Improved SOC)	Relevant everywhere (Specific study: Navarre, Spain)		?	X
Climate change - increased temperature and increased rainfall (Decreased SOC)	Finland	?	?	?
National level obstacle for adapting regional policies (Peatland drainage for agriculture)	Relevant everywhere (Peatlands)	?	?	?
Inadequate and inefficient economic incentives via policy measures (CAP Peatland drainage for agriculture)	Relevant everywhere (Peatlands)	?	?	?
GAEC (Good Agricultural and Environmental Conditions) as part of Common Agricultural Policies (CAP) reform in 2003	Italy	?	?	X
Agri-enviornmental and climate smart policies (leading to afforestation) (Improved SOC)	Austria	X	X	X
Policies and strategies for ensuring soil health and food security (SDG, European Gren Deal, Farm to fork) (Leading to adevelopment and adoption of Soil Improving Cropping Systems (SICS) (Cover srops, mulching, minimum tillage, compcation alleviation) (Decreased slightly SOC)	Relevant everywhere		X	X
Climate agreement to reduce greenhouse emission (leading to afforestation as a CO2 sink) (Improved SOC)	Finland	X	X	X
Societal demand for nature conservation (reflected in Agri-enviornmental and climate smart policies) (Improved SOC)	Austria	X	X	X
Dietary change (Halving protein intake) (Improved SOC)	Relevant everywhere	X	X	X
Reduction of market price (resulting in citrus farm abandonment) (Improved SOC)	Valencia (Spain)	X	X	X
Expansion of rural settlements (reflected in European policy efforts towards rural development) (Decreased SOC)	Austria	X	X	X
Profitability and heterogeneity (harvesting level) (Peatland drainage for agriculture) (Decreased SOC)	Relevant everywhere (Peatland)	X	X	X
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	X
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	X
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	X	X	X
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	X	X	X
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	X	X	X

Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		x	x
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable	Relevant everywhere (field experiments across EU)		x	x

intensification) (potential increase in soil nutrients with increased production)				
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x
Forestry				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Tree species diversification (leads to better SOC retention)	Relevant everywhere	x	x	x
Current plantation practice (stump and residue removal leads to reduced long term C pool)	Relevant everywhere	x	x	x
Changed forest management practices (potential in increasing C pool)	Boreal	x	x	x
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?
Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Management - strategic carbon storage management	Atlantic north	X	X	?
Climate change - increased temperature (decrease in soil organic carbon) (leading to abandonment or reforestation)	France (natural grassland)	X	X	X
Climate change - decreased rainfall (decrease in soil organic carbon) (leading to abandonment or reforestation of natural grassland)	Relevant everywhere	X	X	X
Climate change - increased temperature (reduced potential carbon storage)	Atlantic north (natural grassland)	X	X	
Climate change - drought (decreased soil organic carbon) (Sclerophyllus vegetation and transitional woodland-shrubland))	Spain (Murcia)	X	X	?
Climate change - increased temperature (decreased soil organic carbon) (Sclerophyllus vegetation and transitional woodland-shrubland)	Spain (Murcia)	X	X	?
Climate change - climate projections (increase in soil organic carbon stocks)	Relevant everywhere	?	?	?
Demand change - economic growth (threat to soil related ecosystem services of natural grasslands)	Germany	?	?	?
Demand change - supply and value of climate regulation service (soil organic carbon stock increase due to regeneration, conservation and protection of transitional woodlands)	Portugal (Mountain region)	X	X	X
Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Promote the use of treated sludge from wastewater treatment plants and compost for soil fertilization	Relevant everywhere			x
Increase of atmospheric carbon dioxide and atmospheric nitrogen deposition	Relevant everywhere			x
Cost savings through efficient land use planning and management	Relevant everywhere			x

Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategyf	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil pollution

This document provides an early mapping important drivers for soil health objective 'soil pollution´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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.

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- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

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[1] https://www.eea.europa.eu/publications/TEC25
[2] https://www.bonares.de/socioeconomics/assessment/background-knowledge/dpsir
[3] https://www.soilmissionsupport.eu/news-2022/ontology
[4] https://resoilfoundation.org/wp-content/uploads/2023/06/1.PREPSOIL_Overview-and-WP2_RIMINI_PG_04.05.23.pdf
[5] https://doi.org/10.1136/bmj.n71

Table: List of preliminary drivers (excerpts from the ongoing list of drivers results of literature review), the highlighted drivers are not specific to any soil health objectives. For 'likely to affect' columns, empty cell represents no change, '?' represents unsure/potential change, 'X' represents sure/obvious change.

Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Nitrates Directive of the European Commission in 1991 (decreased fertiliser use leading to improved soil pollution)	Western Europe		X	X
EU policy objectives for energy security (driving increased demand for biofuel production)(no significant difference in pesticide application)	Germany	X	X	X
Population increase and subsequent increase of global demand for food (leading to intensification) (potential increase in the use of herbicides and pesticides)	Relevant everywhere	?	X	?
Promotion and acceptance of the use of organic fertiliser (leading to land application of sewage sludge and compost)(potential micro plastic pollution increase up to 3 to 5 times by 2050)	Germany			X
Increasing global demand (for cereal as food and bioenergy feed) (potential increase of fertiliser)	Ukraine	X	X	?
Warfare activities in relation to land degradation (heavy metal pollution)	Present and past active war zones	X	X	X
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	X
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	X
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	X	X	X
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	X	X	X
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	X	X	X
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	X	X	X
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	X
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X

Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/ conservation farming practice) (unsure soil health objective impact)	Germany (Hesse)		X	X
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		X	X
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	X	?	X
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	X	?	X
Migration (unsure soil health objective impact)	Relevant everywhere	?	X	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	X	X	X
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	X	X	X
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	X	X	X
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	X	X
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		X	X
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	X	X	X

Forestry

Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Acid rain (leading to acidification)	Relevant everywhere	x	x	x
Use of fertilisers	Relevant everywhere	?	?	?
Industrial activities and subsequent air pollution (leading to deposition of heavy metals in the forest floors)	Relevant everywhere	X		
Forest management practices (boreal coniferous forest)	Boreal	X	X	X
Climate change	Relevant everywhere	X	X	X

Drivers	Location	Likely to affect: Land use change	Likely to affect: Land use intensity	Likely to affect: Management quality
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?
Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
None identified so far				
Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Enforcement of good waste management practices for domestic waste (including waste separation, reuse/recycling and minimization of landfilled waste	Relevant everywhere			x
Enforcement of good practices for industrial waste management (including hazardous waste)	Relevant everywhere (industrial and commercial areas)			x
Use of technical design and best available technologies for waste landfilling	Relevant everywhere (Dump sites)			x
Research and implementation of soil remediation techniques on contaminated sites	Relevant everywhere			x
Progress in the management of contaminated sites	Relevant everywhere (industrial and commercial areas)			x
Coordination and alignment across the different directives that limit and control pollution through the different environmental components (air, water and soil)	Relevant everywhere			x
Implementation and enforcement of the revised legislation relevant to industrial pollution (Industrial Emissions Directive)	Relevant everywhere (industrial and commercial areas)			x
Enforcement and periodical revision of the legislation limiting the concentration of pollutants in treated wastewater discharge and sludge treatment (revised Urban Wastewater Treatment Directive and Sewage Sludge Directive)	Relevant everywhere			x
Reform of the Landfill Waste Directive to reduce soil pollution and guarantee soil health	Relevant everywhere			x
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	

Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategyf	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

SOILS FOR EUROPE
SOLO Soil sealing and urban soils

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil sealing

This document provides an early mapping important drivers for soil health objective 'soil sealing´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) as recent examples) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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 task of WP3 is separated across four land uses (agriculture, forest, urban and industrial areas, and natural areas) lead by four task leaders. As per the protocol of the WP3 (link), the ongoing work of WP3 is the creation of an inventory of drivers of changes for different land-uses through a scoping literature review. 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 (e.g. from agriculture to forest, from grassland to urban, use to abandonment)
- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

For additional information, please contact Dr. Shaswati Chowdhury (shaswati.chowdhury@zalf.de) or Prof. Dr. Katharina Helming (helming@zalf.de).

Note: Please do not circulate or cite.

[1] https://www.eea.europa.eu/publications/TEC25
[2] https://www.bonares.de/socioeconomics/assessment/background-knowledge/dpsir
[3] https://www.soilmissionsupport.eu/news-2022/ontology
[4] https://resoilfoundation.org/wp-content/uploads/2023/06/1.PREPSOIL_Overview-and-WP2_RIMINI_PG_04.05.23.pdf
[5] https://doi.org/10.1136/bmj.n71

Table: List of preliminary drivers (excerpts from the ongoing list of drivers results of literature review), the highlighted drivers are not specific to any soil health objectives. For 'likely to affect' columns, empty cell represents no change, '?' represents unsure/potential change, 'X' represents sure/obvious change.

Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Urban land take of arable land (due to tourism, second residence, and associated infrastructure)	Relevant everywhere (Specific locations: Netherlands, Germany (western) Spain (Madrid, Valencia, Valladolid) Italy (Umbria and Po valley), Albania)	x	x	x
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	x
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	x
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	x	x	x
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	x	x	x
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	x	x	x
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	x
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	x	?	x
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of	Germany (Hesse)		x	x

extensive/ conservation farming practice) (unsure soil health objective impact)				
Agri-environmental measures (AEM payments) (leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		x	x
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x
Forestry				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?
Nature				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
None detected so far				
Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Urban relief managment	Relevant everywhere			x
Research and development of efficient impermeable pavements	Relevant everywhere			x

Inclusion of soil sealing management in urban planning strategies	Relevant everywhere	x	x	x
Preservation of biodiversity and ecosystem services in urban and industrial landscapes	Relevant everywhere (Green urban areas)	x	x	
Redevelopment of brownfields and abandoned areas	Relevant everywhere			x
Integration of green infrastructure in urban and industrial areas	Relevant everywhere (continuous urban fabric)			x
Increasing urbanization and industrialization trends	Relevant everywhere (discontinuous urban fabric)			x
Households size and per-capita land consumption	Relevant everywhere (discontinuous urban fabric)	x	x	
Shrinking population	Not sure	x	x	
New logistical platforms for e-commerce	Relevant everywhere (industrial and commercial area)	x		
Expansion of impervious areas due to economic activities and transport infrastructure	Relevant everywhere (industrial and commercial area)	x		
Fluctuations of the real estate market	Relevant everywhere (construction sites)	x	x	
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategyf	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x

Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

WP3: Preliminary list of Drivers for Soil Health to the Think Tank on Soil structure

This document provides an early mapping important drivers for soil health objective 'soil structure (soil compaction) ´ to inform the think tank activities. Following discussions with the think tanks more elaborated, tailored analysis will follow.

The aim of 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. 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[1]) as fundamental components of soil health. The DPSIR (Driving forces, Pressures, States, Impacts, and Responses) framework is a widely-used analytical tool (e.g used in BonaRes[2], SMS[3], PREPSOIL[4]) for understanding the complex relationships between human activities and the environment. The task of WP3 is to identify the drivers which will further feed into the analysis of the links between pressures (soil and land management changes), and states (soil health objectives) and respective impacts (ecosystem services). The outcomes from this analysis is planned to 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 task of WP3 is separated across four land uses (agriculture, forest, urban and industrial areas, and natural areas) lead by four task leaders. As per the protocol of the WP3 (link), the ongoing work of WP3 is the creation of an inventory of drivers of changes for different land-uses through a scoping literature review. 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 (e.g. from agriculture to forest, from grassland to urban, use to abandonment)
- Changes in management (i.e. land use intensity)– drivers of anticipated changes in how the soil and land is managed compared to the present such as changes in regulation, practice, requirements, etc. (e.g. from tillage to reduced tillage; from mono-stands to mixed forests)
- Changes in land management quality (smartness: how well it may integrate multifunctionality and environmental, social and economic services, etc.; e.g. precision agriculture).

The literature review is conducted in accordance to PRISMA[5] protocol. The review is still ongoing and the selected literatures are scanned for a set of values (i.e. likely to affect change, location, land cover type, relevant soil health objectives, relevant stakeholders, likely temporal dynamic, and robustness of knowledge). An excerpt of the ongoing list with few data set is compiled and shared in a table below. Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

Please take a look and communicate feedbacks on the preliminary results and how these results can be better incorporated into think tank (WP2) work with the WP3 partners.

For additional information, please contact Dr. Shaswati Chowdhury (shaswati.chowdhury@zalf.de) or Prof. Dr. Katharina Helming (helming@zalf.de)

Note: Please do not circulate or cite.

[1] https://www.eea.europa.eu/publications/TEC25
[2] https://www.bonares.de/socioeconomics/assessment/background-knowledge/dpsir
[3] https://www.soilmissionsupport.eu/news-2022/ontology
[4] https://resoilfoundation.org/wp-content/uploads/2023/06/1.PREPSOIL_Overview-andWP2_RIMINI_PG_04.05.23.pdf
[5] https://doi.org/10.1136/bmj.n7

Table: List of preliminary drivers (excerpts from the ongoing list of drivers results of literature review), the highlighted drivers are not specific to any soil health objectives. For 'likely to affect' columns, empty cell represents no change, '?' represents unsure/potential change, 'X' represents sure/obvious change.

Agriculture				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Population increase and subsequent increase of global demand for food (leading to intensification)(use of heavy machinery leading to compaction)	Relevant everywhere	X	X	X
Population density (decreasing density correlated to less man made soil compaction)	Italy		X	X
Aging population (resulting in citrus farm abandonment)(Decreased compaction)	Spain (Valencia)	X	X	X
Urban land take (due to tourism, second residence, and associated infrastructure) (Increased compaction)	Relevant everywhere	X	X	X
Increased citizen awareness (impacts potentially all soil health objectives)	Northern Italy	?	?	?
Increasing societal demands for food security (impacts all soil health objectives)	Relevant everywhere	?	?	X
Increasing societal demands for environmental sustainability on land (impacts potentially all soil health objectives)	Relevant everywhere	?	?	X
Non favourable economic condition in rural areas (resulting in farm abandonment)(unsure soil health objective impact)	Relevant everywhere	X	X	X
Increasing demand for bioenergy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Relevant everywhere	X	X	X
Increasing bioenergy production on arable land (decrease of local temperature by 1 degree)	Germany	X	X	X
Urban land take (leading to gradual decline of soil quality)	Greece (Athens)			
Urban land take (economic drivers fuelled by need e.g tourism infrastructure, leading to gradual decline of soil quality)	Spain	X	X	X
Shortages of fresh water resources (playing a decisive role in food production) (unsure soil health objective impact)	Mediterranean	?	?	?
Climate change (leading to mitigation and adaptation strategies, sustainable intensification e.g. using food waste in livestock diets; shifting from monoculture cropping to crop rotation, and, incorporating crop residues into the soil)(increased emission)	Relevant everywhere		?	X
Climate change - Temperature increase (unsure soil health objective impact)	Relevant everywhere	?	?	?
Energy sector and renewable energy policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
EU agricultural policy and agricultural trade policy (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
Environmental policies relevant to agriculture (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
National agricultural policy and policy for the development of rural areas (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact)	Germany (Elbe river basin)	X	?	X
Combined effect of EU level, Country level, and local policy measures (leading to adaptation of extensive/	Germany (Hesse)		X	X

conservation farming practice) (unsure soil health objective impact)				
Agri-environmental measures (AEM payments)(leading to decreased number of livestock per hectare) (unsure soil health objective impact)	Germany		x	x
Common Agricultural Policy (CAP) of the EU (leading to biofuel/maize cultivation in suitable land) (unsure soil health objective impact) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
National legislation: Renewable Energy Act (German: EEG) (leading to biofuel/maize cultivation in suitable land) (ensuring ecosystem services with increased production, unsure soil health objective impact)	Germany (Görlitz)	x	?	x
Migration (unsure soil health objective impact)	Relevant everywhere	?	x	?
Aging population (resulting in farm abandonment of which some are afforested) (increased risk of fire hazard close to settlements)	Spain (west-central)	x	x	x
Remote areas with increasingly very low population density (leading to land abandonment) (unsure soil health objective impact)	Spain (Galicia)	x	x	x
Depopulation of rural areas (resulting in farm abandonment)(Some positive increased SOC, fertility, some negative, erosion, fire hazard, variable, biodiversity based on several factors)	Relevant everywhere	x	x	x
Population increase and subsequent increase of global demand for food (resulting in intensification) (unsure soil health objective impact)	Relevant everywhere	?	x	x
Population increase and subsequent increase of global demand for food with awareness of environmental impact (leading to sustainable intensification) (potential increase in soil nutrients with increased production)	Relevant everywhere (field experiments across EU)		x	x
Internal migration (from centre to the coastal area leading to agricultural land abandonment which turned into forested areas)(increased risk of fire hazard) (unsure soil health objective impact)	Spain (Valencia)	x	x	x
Forestry				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Current forest management and harvesting practice (leading to soil compaction)	Relevant everywhere		?	x
Current plantation practice(boreal coniferous forest) (leading to soil compaction)	Boreal	x	x	x
Forest management practices (boreal coniferous forest)	Boreal	x	x	x
Climate change	Relevant everywhere	x	x	x
Invasive species (Increase of forest pathogens in Europe)	Relevant everywhere	?	?	?
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
None identified so far				

Urban and industrial				
Drivers	Location	Likely to affect		
		Land use change	Land use intensity	Management quality
Increasing groundwater abstractions as a result of concurrent residential and agricultural land/water uses	Relevant everywhere	?	?	?
Cost savings through efficient land use planning and management	Relevant everywhere			x
Funding of research and innovation programmes and projects	Relevant everywhere		x	x
Encourage the use of citizen science as a form of consistent soil health monitoring and development of a framework that allows the efficient use of such data	Relevant everywhere			x
Bottom-up de-sealing initiatives	Relevant everywhere		x	x
Recognition of the role of green spaces in enhancing quality of life in urban areas	Relevant everywhere			x
Population growth in urban areas	Relevant everywhere	x	x	
Declining rural population	Relevant everywhere	x	x	
Passing and implementation of legislation that standardizes the monitoring framework of Soil health (Soil monitoring Law)	Relevant everywhere			x
Implementation of the EU Soil Strategyf	Relevant everywhere	x	x	x
Enactment of laws that guarantee the fulfilment of the goals proposed in the European Green Deal and Zero Pollution Action Plan	Relevant everywhere			x
Implementation of the EU Nature Restoration Law	Relevant everywhere			x
Funding and development of projects through the Soil Mission	Relevant everywhere			x
EU-level urban greening policies (BDS2030 and Nature restoration law)	Relevant everywhere	x		x
Soil sealing offsetting policies and strategies	Relevant everywhere			x
International level legislation to protect and restore soil ecosystems	Relevant everywhere			x
Research demands by EC	Relevant everywhere	x	x	x
Climate change	Relevant everywhere	x	x	x
Shift in precipitation and temperature patterns	Relevant everywhere		x	x
Increasing recognition of the importance of soil health for ecosystem functioning	Relevant everywhere	x	x	
Adoption of digital platforms for soil health monitoring and information sharing	Relevant everywhere		x	x
Development of standardized soil health indicators in urban areas	Relevant everywhere	x	x	x
Integration of data analytics and remote sensing for land use planning	Relevant everywhere	x	x	x
Advancements in soil monitoring technologies	Relevant everywhere		x	x

Appendix 3

SOLO
Soils for Europe

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Position statement: BonaRes Repository as trusted repository in accordance with Horizon Europe criteria

Actuality: 19.9.2024

Contact: Nikolai Svoboda (svoboda@zalf.de)

Trusted repositories are defined by Horizon Europe as either

- Certified repositories (e.g., CoreTrustSeal, nestor Seal DIN31644, ISO16363) or disciplinary and domain repositories commonly used and endorsed by the research communities. Such repositories should be recognized internationally.

- General-purpose repositories or institutional repositories that present the essential characteristics of trusted repositories.

The BonaRes Repository is currently in the process of obtaining CoreTrustSeal certification. Reviewer feedback is being addressed, and the certification is anticipated to be completed by 2024. Additionally, the BonaRes Repository is recognized as an open access repository in both the 'DFG RIsources' (https://risources.dfg.de/detail/RI_00508_en.html) and 'OpenDOAR' (https://v2.sherpa.ac.uk/id/repository/10039) directories. The BonaRes Repository is an internationally recognized, domain specific repository for agricultural research data, funded and perpetuated at the institutional level.

Requirements and characteristics of a trusted repository and realization in the BonaRes Repository (BR)

- Trusted repositories display specific characteristics of organizational, technical and procedural quality such as services, mechanisms and/or provisions that are intended to secure the integrity and authenticity of their contents, thus facilitating their use and reuse in the short- and long-term.
  - BR makes use of technical measures such as digital signatures (e.g., the creation of MD5 hashes during data ingestion) and time stamps to ensure (data) integrity and authenticity as well as protection against (data) falsification.
- Trusted repositories have specific provisions in place and offer explicit information online about their policies, which define their services (e.g. acquisition, access, security of content, long-term sustainability of service including funding etc.).
  - A continuously adapted online help (FAIRagro Helpdesk) and personal data stewards support (support-data@bonares.de) is provided, as well as guidelines (https://doi.org/10.20387/bonares-mvkn-a4mb) on publishing research data. Explicit information about services is published in the BonaRes Data Policy (https://doi.org/https://doi.org/10.20387/BonaRes-RYCV-30RK).
- Provide broad, equitable and ideally open access to content free at the point of use, as appropriate, and respect applicable legal and ethical limitations.
  - Published resources, including data and metadata, are openly accessible in line with the open access paradigm. In cases where a temporary embargo is in place, metadata remains freely available while access to the data is restricted. During this period, contact to the author to request data access is ensured.
- They assign persistent unique identifiers to contents (e.g. DOIs, handles, etc.), such that the contents (publications, data and other research outputs) are unequivocally referenced and thus citable.

    - Once published in BR, each dataset is assigned to a DOI (prefixes: https://doi.org/10.20387 and https://doi.org/10.4228). These DOIs are registered with DataCite through the TIB (German National Library of Science and Technology).
- They ensure that contents are accompanied by metadata sufficiently detailed and of high quality to enable discovery, reuse and citation and contain information about provenance and licensing; metadata are machine-actionable and standardized (e.g. Dublin Core, Data Cite etc.) preferably using common non-proprietary formats and following the standards of the respective community the repository serves, where applicable.
    - Data is described by descriptive and administrative metadata (following DataCite and INSPIRE standards), including licensing details such as 'Creative Commons CC-BY' licenses. The metadata is human-readable within the repository and can be downloaded as a PDF. Additionally, the metadata is machine-actionable, available in XML format (ISO 19139:2007) and as JSON in schema.org format via API access.

- Facilitate mid-and long-term preservation of the deposited material.
    - Long-term storage is ensured for a minimum of ten years using ZALF's own infrastructure resources. For archiving beyond ten years, including bit-stream-preservation, migration, and metadata curation, the repository collaborates with external partners to ensure sustained preservation.

- They have mechanisms or provisions for expert curation and quality assurance for the accuracy and integrity of datasets and metadata, as well as procedures to liaise with depositors where issues are detected.
    - Metadata are reviewed by data stewards before publication and during ingestion. If any issues are identified, established procedures ensure direct communication with the authors. Authors must have a valid user account in the repository, including a valid email address. During submission, a ticket is generated containing the author's and institution's contact information. This is used for all further communication between author and data stewards (editorial team) until the data are published.

- They meet generally accepted international and national criteria for security to prevent unauthorized access and release of content and have different levels of security depending on the sensitivity of the data being deposited to maintain privacy and confidentiality.
    - Data publication is carried out by the data stewards, not by the authors.
    - Only authorized data stewards can change data and metadata once published; each alteration is documented in the lineage element of the metadata and thus transparent.
    - Sensitive research data is sufficiently anonymized before publication.
    - All sensitive personal data is managed according to the GDPR rules.

Conclusion

From the standpoint of the ZALF Research Data Management, researchers applying for funding in the Horizon Europe program should be able to use the BonaRes Repository for the publication of their research data. The BonaRes Repository is expected to receive trusted repository certification by the end of 2024, at latest by 2025.

Repository requirements as referenced from European Commission (2021). EU Grants: AGA — Annotated Model Grant Agreement: V1.0 1.5.2025. EU Programmes 2021-2027. HE. Horizon Europe and Euratom. https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/common/guidance/aga_en.pdf (see p. 376ff).