HORIZON-MISS-2021-SOIL-01-01 /
Preparing the ground for healthy soils:
Building capacities for engagement, outreach and knowledge
PREPSOIL – 2022-2025

PREPSOIL DELIVERABLE

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Executive Summary

This Regionally focussed Strategic research and innovation agenda brings together the needs for new knowledge via R&I - including in co-creation - based on soil needs assessments in 21 typical regions across different land use types in Europe (as reported in PREPSOIL D2.1, Bayer et al., 2023). This is then linked with an analysis of challenges and enabling conditions for the Development of Soil Health Living Labs across Europe. Soil health is crucial for addressing climate change and socio-economic challenges across Europe, and to tackle these issues, region-specific, innovative solutions are necessary. The Soil Health Living Labs (LLs), outlined in the Mission Soil framework, offer a collaborative approach to develop these solutions through co-creation among stakeholders. In a final chapter we discuss the enabling conditions required for successful implementation of Soil Health LLs, including long-term funding, policy alignment, and landscape-level approaches.

The research and innovation needs at the regional level are categorized into four sections: scientific process-oriented research, co-created innovation in Living Labs, data measurement and monitoring, and up and out-scaling. These knowledge needs are listed as: i) general needs across Europe and land uses; for example definitions and soil literacy needs; ii) Knowledge needs per land use: agriculture, forestry, urban areas and mixed land use regions; iii) specific knowledge needs for north, south, west and east Europe.

The **overarching key research and innovation needs across Europe** include developing clear definitions for soil health, transparent modeling of soil dynamics, and understanding synergies between soil health and other sectors. Co-created innovations should focus on guidelines, decision tools, and long-term financing for Living Labs. Monitoring efforts include harmonized indicators and cost-effective methods, while upscaling focuses on overcoming barriers and improving soil literacy.

When looking specifically at **agricultural systems** in Europe face diverse challenges requiring tailored solutions for soil health. Key knowledge needs include integrating landscape and ecosystem views, improving soil biological assessments, developing sustainable crop systems, fostering farmer collaboration through living labs, and creating cost-effective monitoring systems. Socio-economic and policy research is essential for scaling sustainable practices. Different regions in Europe face unique soil challenges. Northern Europe requires innovations in drainage, aeration, and peatland conservation. Southern Europe needs solutions for drought, erosion, and salinization. Western Europe focuses on regenerative farming and carbon sequestration, while Eastern Europe emphasizes water retention and organic farming to address degradation and improve soil fertility.

When looking specifically at **forestry knowledge and innovation needs** additional things pop up like: the need for Scaling EU-wide soil missions for forests to adapt strategies to long forestry rotation cycles. Multi-stakeholder approaches, including collaboration between forest owners and researchers, are essential for co-created innovation. Improved data collection, risk assessment models, and monitoring systems will support forest management and EU policies on soil health. In forests also significant regional differences exist. In the North, improve forest management to prevent soil damage and enhance carbon sequestration. In the Southeast, raise awareness on soil health and tourism impacts. In the West, focus on peatland rewetting and sustainable wood-biomass practices. In the East, shift to mixed-culture forestry and improve soil management and tourism infrastructure.

Research and innovation needs **for urban and (post)industrial land** focus on avoiding soil sealing by developing monitoring tools, raising awareness, and promoting smart planning. Key areas include improving knowledge on pollution impacts, creating cost-effective mapping methods, and encouraging knowledge exchange and restoration incentives through co-created innovation and upscaling. Research needs across Europe focus on urban soil health challenges. R&I needs for urban and industrial areas vary across Europe, influenced by climate, landscape, demographics, and socio-economic conditions. Factors like urbanization, environmental policies, and data availability affect soil management, with varying legislation and monitoring systems across countries impacting redevelopment and land use strategies. In the North, managing soil sealing and compaction in cities is crucial. Eastern Europe requires research on soil contamination and monitoring systems. Southern Europe needs studies on soil degradation and water retention. Western Europe faces challenges with policy implementation and balancing urban growth with soil conservation.

Lastly there are places where **land uses are mixed or changing**. Such as land abandonment, peatland rewetting, pressure of tourism on soils and peri-urban areas. These areas call for specific approaches and solutions.

The main barriers for successful implementation of LLs and LHs are listed as financial, technical, institutional, policy-related, cultural/social. Also soil literacy is of importance. The awareness on the matter drives decision making and the willingness to change. In addition, potential solutions are illustrated to mitigate these barriers, first the barriers for starting the cocreation in a LL setting, then the barriers for implementing practices to improve soil health by sustainable soil management.

Lastly, a future outlook suggest to focus on three strategies: i) **Long-Term Funding Strategies** Supporting LL Implementation such as long-term funding is discussed as it vital for the successful implementation of Soil Health LLs. Soil health innovations often take time to show results, so continuous collaboration beyond typical research project cycles is crucial. LLs are iterative processes, where trust and cooperation among stakeholders, including farmers, land managers, and policymakers, are key. **A long-term commitment from all parties** is necessary for developing sustainable soil health practices. Furthermore, the policy for Soil Needs Alleviation is discussed.

ii) **Policy coherence across sectors** is essential including funding schemes. The integration of research and innovation policies, environmental policies, agricultural policies (e.g., CAP), and climate change policies is key. Policymakers should be engaged throughout the R&I process to ensure alignment between research outcomes and sectoral policies. Financial matching schemes that bring together public and private sectors are an effective way to incentivize investments in soil health. Creating a "Science-Policy-Society" interface allows policymakers to incorporate real-time data from LLs into policy development, ensuring that innovations are in line with societal needs and environmental goals; iii) The success of Soil Health LLs depends on a **landscape-level and value chain/food systems approach,** extending beyond individual farms to address broader ecological and socio-economic contexts. Soil health challenges are influenced by factors like soil type, topography, and local ecosystems, and thus LLs must consider these variations. Collaboration among stakeholders at the landscape level is crucial for developing integrated land use plans. By including farmers, landowners, and policymakers in the decision-making process, LLs can help create more sustainable and context-specific soil management practices. These enabling conditions are crucial in supporting the transition to sustainable soil management practices, addressing the urgent challenges posed by climate change and socio-economic pressures across the continent.

Chapter 1: Introduction

The Mission 'A Soil Deal for Europe' (from now on, the Mission Soil (EU, 2022) states that the **lack of knowledge and awareness** of the importance of long-term soil health for different stakeholders – land managers, industries, consumers and society at large – is a **major driver of soil degradation** affecting its capacity to provide ecosystem services. Raising awareness and knowledge on soil health will assist in a successful Mission deployment in two ways: more people will identify themselves as **soil stewards**, and managers and authorities will have the necessary knowledge to improve practice and **implement effective actions**. Within this context, **PREPSOIL**'s **main objective was to facilitate the deployment of the Mission across European regions,** achieved through **(i) the co-creation and roll out of tools and spaces for interaction, knowledge-sharing and co-learning,** and **(ii) stocktaking and dialogue** to understand how regional 'soil needs' assessment, supported by harmonised monitoring mechanisms, can then lead to action in Living Labs (LLs) and Light Houses (LHs) for soil health. Soil Needs are defined as 't*he requirements from existing and emerging socio-economic and geo-biophysical perspectives that determine soil health and related services to human society*' (Bayer et al., 2023).

The Mission Soil Living Labs are *user-centred, place-based and transdisciplinary research and innovation ecosystems that involve multiple partners (e.g., land managers, scientists, citizens, businesses, and local authorities) to co-design, test, monitor and evaluate solutions in real-life settings for improving soil health* (EU, 2023). The LLs involve partner from different backgrounds and sectors and comprise of multiple sites. Each LL focusses on a specific soil challenge which can comprise of various locations such as farms, forests, and industrial areas. These sites have then the potential to evolve into LHs, which are *sites for demonstration of exemplary solutions, training, peer-to-peer learning, and communications related to improving soil health*. LLs and LHs are particularly useful tools to give space to the regional differences in terms of land use, land management strategies, culture, political, social structure and economic situations. The up and out-scaling of proven successful management strategies is also facilitated by these regionally based approaches. To further facilitate these processes, research and innovations needs to drive the transition needed towards healthy soils in Europe. Drivers were assessed using an European wide soil need assessment using the DPSIR methodology (Helming et al., 2018) to evaluate the different drivers of change, processes that lie at the basis of the soil needs, the current state of soils and the way people use it, the impact the soil state has on the biophysical and socio-economic situation, and the possible solutions that could be implemented to mitigate the issues that are forming the barriers for change in every specific area.

This document aims to bring together the results of a synthesis of insights generated in PREPSOIL and relevant programmes such as EJP SOIL and projects under the Mission Soil. The document is a region-focused research and innovation agenda that aims to guide the implementation of the Mission Soil's ambition to roll out successful LLs and LHs across Europe and identify soil needs related to the transitional change needed to adapt to biophysical and socio-economic changes. For this, for each land use (agriculture, forestry, natural areas, urban and industrial areas, and mixed land uses) the most important drivers, constraints and research and innovation gaps were identified for four regions in Europe (North, South, East, West). An overarching future outlook highlights important actions that need to be taken in the near future to secure important elements of the output will be i) Research and Innovation needs for soil health including the landscape/ecosystem view; ii) inventory of co-created innovation needs such as capacity building, science broking and awareness raising; iii) development of monitoring and verification needs such as indicators, monitoring techniques and data management; and iv) ways to scale up and scale out good practices, including policy and socio-economic constraints and opportunities for LL/LH design, including business plans.

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Goal of the document: highlighting research and innovation needs that will enable LLs/LHs to be established and improved; and why LLs/LHs are key to systems innovation and which barriers and opportunities exist for different land uses and regions across Europe.

Guide for the research and innovation agenda

In the first chapter, this roadmap's purpose and the general definitions used in the document are defined. Chapter 2 explains the building blocks used for the research and innovation agenda. Chapter 3 highlights the EU-wide soil needs to facilitate sustainable soil management on regional scale adoption. In chapter 4, 5, 6 and 7 an overview is given of the research and innovation needs for facilitating the development of Living Labs and Lighthouses for each land use based on the information extracted from the building blocks (chapter 4 for agriculture, chapter 5 for forests, chapter 6 for urban and industrial areas and chapter 7 for changing and mixed land uses). Special attention is given to what kind of research and innovations are needed/ and are done in LLs/LHs and what kind of research is needed for LL implementation. As the return time is different for each land use, a multitude of opportunities, research and barriers are identified for each land use and specified for the different regions in Europe. Chapter 8 dives into different barriers and opportunities for the delivery of soil health at the regional scale. Chapter 5 gives an outlook of the next steps recommended to be taken in terms of prioritizing research and innovation in Europe.

Glossary

1. *Soil Health:* the continued capacity of soils to support ecosystem services, assessed through a set of proposed, measurable indicators (Implementation plan, p. 5, (SWD (2023) 323 final, p. 5))
2. *Mission Soil Living Labs (LL)* are user-centred, place-based and transdisciplinary research and innovation ecosystems that involve multiple partners to co-design, test, monitor and evaluate solutions in real-life settings for improving soil health. Living Labs comprise multiple Experimentation Sites that vary by land use type – agriculture, (peri-)urban, forestry, (post-) industrial, and natural environments – By working in real settings, Mission Soil Living Labs ensure that solutions are both practical and adoptable (EC, 2023).
3. *Lighthouses (LH)* are experimentation sites where exemplary performances in terms of soil health improvements, serve as models for effective soil management (EC, 2023).
4. *Drivers* that improve soil health management (Helming et al., 2018).
5. Precautionary soil management *pressures* (Helming et al., 2018).
6. *States* that, when combined, form healthy soils (Helming et al., 2018).
7. *Impacts* that are beneficial to ecosystems and humans (Helming et al., 2018).
8. *Responses* that protect soils or limit ecosystem service decline (Helming et al., 2018)
9. *Soil needs:* the requirements from existing and emerging socio-economic and geo-biophysical perspectives that determine soil health and related services to human society (Bayer et al., submitted).
10. *Ecosystem service:* Ecosystem services or eco-services are defined as the goods and services provided by ecosystems to humans
11. *Quadruple Helix Model:* The quadruple and quintuple innovation helix framework describes university-industry-government-public-environment interactions within a knowledge economy
12. *Smart Specialization Strategies:* an innovation policy concept that aims to boost regional innovation, contributing to growth and prosperity by helping and enabling regions to focus on their strengths. Smart Specialization is based on partnerships between businesses, public entities and knowledge institutions.

13. *Entrepreneurial Discovery Processes*: Entrepreneurial discovery is an interactive and inclusive process in which the relevant actors identify new and potential activities and inform the government.

Chapter 2: Building blocks and concepts

2.1 Introduction

For the assessment of the Soil Needs across Europe we build upon several elements (Fig. 1). The first source of information was the work done in the first year of PREPSOIL on the soil needs assessment across Europe. In this task 20 regions (Fig 2) were selected of the basis of several key identifiers: geographical location, soil type (mineral vs organic), land use type (urban/post-industrial, agriculture, forest/nature) where the soil needs were collected using the DPSIR approach (Fig 3). The second building block is the combined information from the Nati00ns and SOILL-start-up projects that are reviewing the specific needs of the Living Labs. The third building block are the roadmaps that have been made/are being made on soils, the Soil Mission Support (SMS) project, EJP SOIL and SOLO. Fourth is a wide review insight of pilot and demonstration site in projects running under the Soil Mission project. The last building block is the information that was generated in the SMS project, a compact roadmap for all soil mission objectives and an ontology.

Figure 1: Building Blocks of the PREPSOIL Strategic Research and Innovation Agenda (STRIA)

2.2 Soil Needs assessment WP2 PREPSOIL using DPSIR

The 20 regions were selected on their representativeness in terms of land use, soil type, geographical location, climate, relief and socio-economic conditions to make sure that most Europeans would recognize themselves in one of the 20 regions (fig 2).

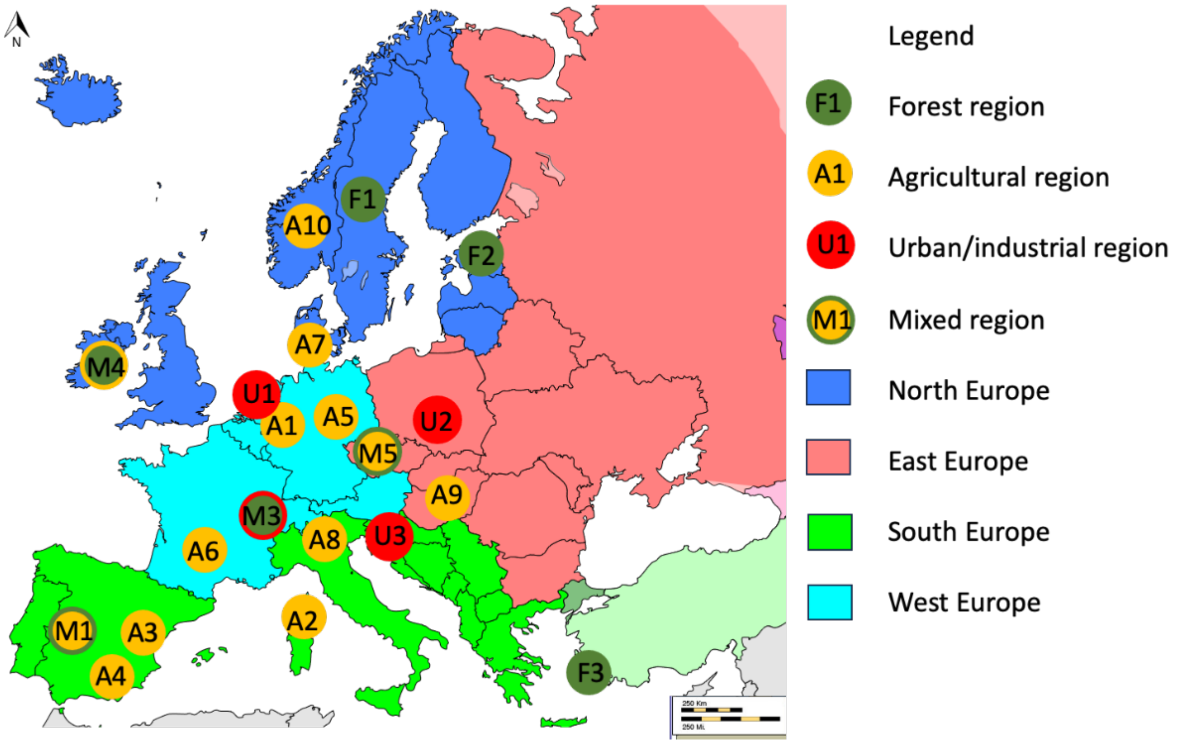
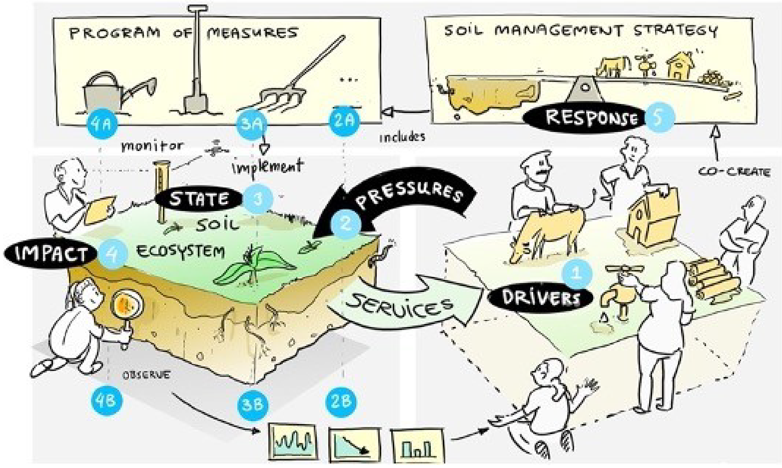


Figure 2: Selected regions for the soil needs assessment (EuroVoc).

The soil needs assessment (SNA) was constructed as an interdisciplinary and participatory research approach that combines natural science knowledge on the functioning of soils and ecosystem services with research methods from social sciences. Expert knowledge and literature analyses were combined with participatory methods to collect stakeholder perspectives as well as to generate awareness and literacy on the importance of soils.

The research was conducted along the five categories of the Driver- Pressure-State-Impact-Response (DPSIR) framework (Fig. 3). The framework categorises human-environmental system interactions in addressing external drivers for decision making on land use and soil management, respective effects on soil health, ecosystem services impacts and options for soil improving response measures. Such system interactions are subject to regional variations. Our focus was to reflect the diversity of European land use types, socio-economic and geo-biophysical conditions of soils. For this purpose, 20 representative regions across Europe were selected that represent systems in agricultural production, forestry, urban and (post)industrial, and mixed land uses in different parts of Europe with different soil types. More than 500 stakeholders representing farmers, policy, government, advisors, research, business, civil society organizations and non-profit government organizations interacted during the participatory research process. The results are presented in D2.1 of the PREPSOIL project (Bayer et al., 2023: https://zenodo.org/records/12743276).



3b: DPSIR Levels
Level 1: Drivers: External trends, shocks, demand changes, degradation forces, involved stakeholders, involved natural processes
Level 2: Pressure: Which soil needs appear, Soil management needs
Level 3: State: Determine status of soil health
Level 4: Impact: Trade-offs of changing state, Impact of changing state
Level 5: Response (soil strategy incl. POM): Options for soil health improvement, Which stakeholders, Soil policy needs, Soil information needs

Figure 3: the DPSIR (Driver, Pressure, State, Impact, Response) framework for developing a soil management strategy that includes a program of measures for soil needs a: graphical representation developed in the SMS project, (Nougues and Brils, 2022). 3b: table with key identifiers of the DPSIR levels used in PREPSOIL.

Key Recommendations derived from the soil needs assessments (Bayer et al., 2023) were used in the different sections of this STRIA.

2.3 Building block: information from PREPSOIL WP4/NAT100NS/SOILL-startup

The overarching goal of the Soil Mission is to establish 100 living labs and lighthouses to facilitate that all soils in Europe will be healthy in 2050. This goal intrinsically means that the focus of the activities needs to be on the ground, in the regions, with the stakeholders that manage the soil. First steps were taken by the SMS project where the first LL and actor needs assessment was made. This work was followed up by WP4 of PREPSOIL, the Nati00ns project and the SOILL-startup project that aim to give guidance to the new living labs that are under development in the Soil Mission. These consecutive (part of) projects identified LLs/LHs needs on topics such as soil education, define business models and monitoring options. The main knowledge gaps identified by these projects are key to the success of the soil mission and with that the fate of the European soil's health.

LLs are ideal spaces for testing innovations; not only technical innovations but an innovation space/ecosystem that exhibits a high degree of complexity, characterized by varying degrees of adoption of the Quadruple Helix Model (Carayannis and Campbell, 2009) and diverse interactions with Smart Specialization Strategies and their associated Entrepreneurial Discovery Processes. Within these ecosystems, orchestrators and key stakeholders play a crucial role in governance, providing leadership in shaping innovation policies at local, regional, national, and international levels. Essential factors for the success of local and regional innovation ecosystems include strong leadership, the ability to attract and retain talent, the presence of a research and innovation infrastructure, a well-connected network of complementary stakeholders, and a focus on internationalization. In the SOILL-startup project the main goal is to facilitate and foster collaboration among the Living Labs and key EU and international stakeholders. By creating synergies and aligning efforts and shared resources, SOILL-Startup envisions a collaborative ecosystem where innovative solutions for soil health are developed, co-created, and disseminated widely. One key element is the Soil Health Learning Journey on which all LLs can embark (see www.climate-kic.org/opinion/caring-for-soils-measure-monitor-manage/).

2.4 Building block: Roadmaps

In a number of past and running projects roadmaps for research have been made; or are currently under development. The first roadmap for the Soil Mission was made by the Soil Mission Support (**SMS**) project, where a rough outline of the needed future steps (near and longer future) to ensure reaching the goals (Ittner & Nauman, 2022). The SMS roadmap was based on a comprehensive literature analysis (Mason et al., 2023) combined with a voluntary EU wide stakeholder consultation. It addressed all land use types in Europe and followed an INput-Output-Outcome-Impact (IOOI) logic to classify research and innovation needs.

The second important roadmap is one on agricultural soil management that is made in the **EJP SOIL** project, that aims to give guidance to the next 10 years of research an innovation for agricultural soils. The EJP SOIL roadmap has a strong focus on a climate mitigation and adaptation and the role of agricultural soils in that (Keesstra et al., 2025). But also soil threats such as compaction received attention. In addition, the role of education, long-term field experiments (LTE) and how to apply scientific knowledge in policy and by farmers was a point of attention. The roadmap was based on i) extensive interviews, workshops and questionnaires with the National Hubs in each EJP SOIL country (24) to collect knowledge needs, barriers and opportunities; ii) a synthesis of all EJP SOIL project results, revealing the remaining knowledge gaps (for knowledge development; knowledge sharing, knowledge harmonization and knowledge application); and iii) an EU-wide open consultation on the roadmap.

In this PREPSOIL roadmap, some key recommendations of the EJP SOIL roadmap (Keesstra et al., 2025) are coming back in the overarching research and innovation needs and especially in the part dealing with agricultural soils.

The SOLO project picked up after the SMS project for all specific objectives of the Soil Mission. These roadmaps have a broad view on each of the soil health objectives (ref). Specific attention is being given to the soil ecosystem. These roadmaps are based on expert based thinktanks for each specific objective and an EU-wide open consultation. Key recommendations of the roadmaps on soil sealing and pollution were used in the PREPSOIL roadmap for the recommendation in the section on urban and industrial areas. The other SOLO roadmaps served as reference material for the agriculture and forestry section of this STRIA.

2.5 Building Block Mission Soil board recommendations

The mission board formulated the following key recommendations for the implementation of the LLs (Campodonico et al., 2024):

Early Engagement and Capacity: In the early phases, promoting awareness around Living Labs required extensive efforts to convey their innovative potential. Meaningful Living Labs begin with the active involvement of existing local communities, highlighting the importance of robust engagement and capacity building from the outset. Effective early outreach and training for stakeholders allow local communities to appreciate how Living Labs can serve as catalysts for innovative, community-based solutions to soil health challenges.

Inclusive, Bottom-Up Participation: Securing meaningful involvement of farmers, foresters, urban gardeners, and other relevant actors in the Living Lab is essential to ensure that solutions reflect regional needs. Stronger local facilitation can enhance this bottom-up approach, tailoring collaborative processes to regional capacities and fostering solutions that are genuinely co-created with the people most affected by soil health issues.

Cross-Sectoral Coordination: Collaboration across sectors such as agriculture, forestry, and urban areas is crucial for comprehensive soil health. Addressing this complexity requires structured, early cross-sectoral dialogue and incentives to support coordinated action on soil health. This approach facilitates the alignment of sector-specific insights and builds a holistic foundation for broader systemic impact.

Boosting Soil Literacy Among Key Stakeholders: Low soil literacy among stakeholders limits adoption of new practices. Targeted education and capacity-building campaigns help farmers, land managers, and planners understand and implement sustainable soil practices, equipping them to support long-term soil health and sustainability.

Balancing Scalability with Context- Specific Solutions: For Living Labs to succeed, solutions must be adaptable to local contexts yet scalable. Tailoring innovations to local conditions addresses challenges while generating scalable knowledge that can support application across regions.

Policy Alignment and stability for scalable Impact: Aligning soil health efforts with EU policies like the Common Agricultural Policy and Green Deal strengthens their impact. Integrating soil health into these frameworks provides political and financial support, facilitating a unified, comprehensive approach to sustainable soil management.

Tackling Soil Degradation Through Data and Indicators: With 60% of European soils degraded (Ferreira et al., 2022), data-driven strategies are essential for monitoring and improving soil health. Reliable indicators and long-term data collection enable regions to adapt soil practices effectively. Living Labs play a key role in applying adaptable, science-based approaches tailored to the diverse and local ecosystem, fostering resilience and adaptive management.

Bridging Knowledge and Policy Gaps: Closing the gap between knowledge and local policy implementation is critical for soil health. Engaging stakeholders, including citizens, turns scientific insights into actionable practices, promoting the adoption of soil health measures. Local involvement ensures policies are well- understood and practicable.

Financial Support for Soil Transition: Ongoing financial support is crucial for soil restoration, with tools like the Common Agricultural Policy providing essential funding. Coordinated finances allow Living Labs to maintain momentum and scale impact, enabling them to focus on region-specific needs and expand their reach across Europe.

Chapter 3: Research and innovation needs across Europe: a knowledge framework for enabling Living Lab and Lighthouses

3.1 Introduction

The research and innovation needs that are relevant on a regional level are grouped into four sections, inspired by the roadmap organization of the EJP SOIL and the operational objectives of the Soil Mission. The knowledge framework is focused on the research and – in parallel – innovation in co-creation as implemented in successful LLs and LHs (Fig 4). The first compartment comprises the scientific process-oriented research, which has a wide scope from mechanistic understanding from controlled experiments and modelling to economic and social research. Improving the basic and strategic research base is a prerequisite for interpretation and learning from the context dependent and praxis-oriented co-creation for innovations. The second compartment is about co-created innovation, which is the basic idea behind the Living Labs, which forms the backbone of the Mission Soil. This includes innovations in actual soil management, understanding of socio-economic conditions for implementation of changes and research at a meta-level in the functionalities of the co-creation processes in LLs. The interaction between research and co-creation may be reinforced using a modernization of the classical "Mother-Baby trial approach. This is an on-farm participatory set-up to co-innovate and test technology options in a combination of researcher controlled "Mother experiments" with replications and farmer controlled "baby-trials" mirroring the mother trial but with selected treatments (Rusike et al., 2005; Reddy et al., 2015).

The third compartment is about data; can we measure, monitor and verify at needed scale and precision? The last compartment is about up and out-scaling. What kind of barriers and opportunities exist for rolling out the LLs and LHs sustainable approaches. What kind of capacity building is needed. Is existing knowledge reaching the people that need it? Are they even aware of their knowledge need? Here the attention lies on research and innovation that is needed in terms of good governance, cultural acceptance and the science-policy interface. This chapter discussed elements that are relevant for all land-uses. The highlighted topics were synthesized from the different building blocks introduced in chapter 2.

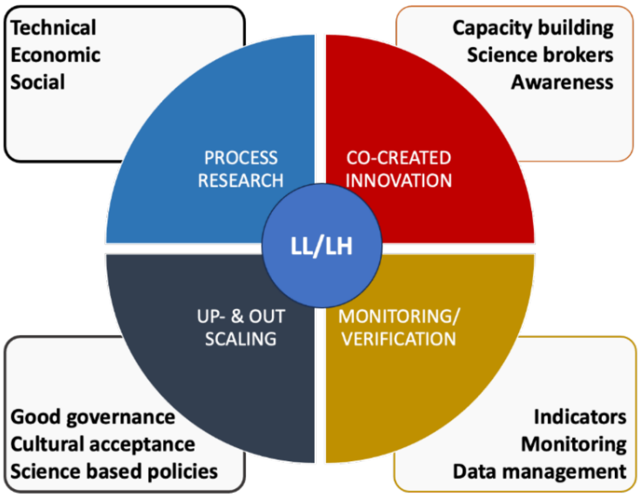


Figure 4: knowledge framework targeting the LLs and LHs knowledge needs (Keesstra et al., 2024; Dalkir, 2005).

For each of the compartments of our LL focussed knowledge framework we identified some key knowledge needs. Some of these knowledge needs are more overarching then only for the establishment and successful implementation of LLs, but are highlighted here as they are seen as key requirement for the LLs to be successful.

3.2 Process research (Technical, economic, social)

List of research and innovation needs on EU scale

- Come to a consensus of clear definitions and ontologies for "soil health" and Soil Mission Objectives (e.g. land degradation, soil sealing, soil footprint) to create a common understanding and provide a basis for measuring progress
- Development of transparent modelling approaches to simulate soil health dynamics (degradation or remediation) and to assess the impact of changes in land management on soil functions such as soil organic carbon storage, greenhouse gas emissions, biological activity, or water retention to prevent droughts and floods
- Synergies and trade-offs between soil health objectives and human health, climate action, water cycle/quality, biodiversity, and food security.
- Optimize the saving and reusing existing data to avoid repetition of research efforts, making use of existing databases and upcoming harmonized EUSO database.
- Perform multidisciplinary research on barriers for sustainable soil management adoption.
- Incorporate landscape and regional approaches in sustainable soil management research.

3.3 Co-created innovation

- The co-development of (action- and practice-oriented) guidelines and decision-making tools with and for stakeholders involved in soil management and remediation, bringing together existing knowledge.
- The implementation of living labs may be an opportunity to co-develop soil health solutions but need to be equipped from bottom up and financed at long term.
- Promote life-long learning for different stakeholders.
- Inventory of policy and socio-economic constraints and opportunities for LL/LH design and implementation including business plans;
- Maintain the key science-policy interface developed in EJP SOIL and connection between international networks related to soils, to be even developed further. This will ensure that soils are taken into consideration when land use decisions are made at all levels starting from regional to national and European.
- Science-policy: use the extended National Hubs in all European countries to organise exchanges between national policy makers and scientists in each member state, especially focussing on each of the main EU regulation (e.g. the proposed EU Directive on Soil Monitoring and Resilience, CRCF, CAP) to know the specific knowledge needs from policy makers in each country.

3.4 Monitoring and verification

- Further develop agreed, shared, harmonised indicators for all Soil Mission Objectives, accompanied by interpretative values (e.g. threshold, normal operating ranges, target values) reflecting on soil type, land use, climate to support decision-making
- Develop cost-effective methods for calculating and measuring the harmonised indicators to facilitate their implementation in large-scale monitoring programmes and collect relevant data
- Development and testing of new methods of monitoring soil status using remote sensing, citizen science and field sensors

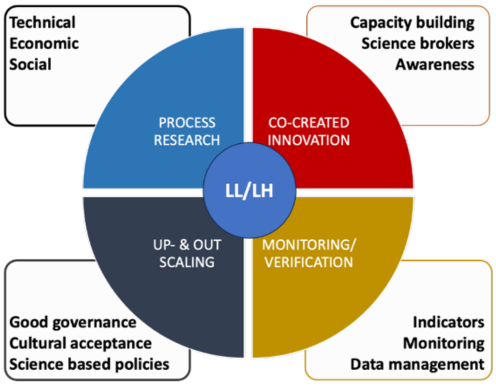
- Create harmonized spatial maps to identify areas impacted by degradation or pollution, hotspots of biodiversity or carbon stocks, eroded land or land prone to erosion, etc., to support decisions and actions to address these impacts
- Maintain the network of long-term experimental sites as was developed under the EJP SOIL.
- Further harmonize laboratory methods and sampling protocols transfer functions, essential for estimating soil properties, require meticulous calibration and validation to ensure accuracy and reliability across diverse conditions.
- Improve the definition and continue testing of soil indicators and determine reference values/thresholds for the different soil indicators that are needed for the EU policies depending on local conditions (soil, climate, land use).

3.4 Up and outscaling

- Identify and develop solutions for barriers to start land management changes to improve soil health related to policy regulations, value chain lock-ins, societal/perception issues, financial drawbacks etc.)
- Assessment of socio-economic conditions and barriers for implementing solutions and practices, accompanied by new business models for land users/owners
- Assessment of successful policies and economic incentives for farmers, foresters, land users and city developers which target the provision of soil-based ecosystem services alongside business activities to meet societal demand from soils.
- Improved soil literacy and attention for the importance of soil among key actors involved in soil and land management, decision-makers and the general public. This requires tailored communication to each target group on the role of soil and solutions to ensure that soil services and benefits can be provided.
- The soil needs assessment approach reported by Bayer et al., *submitted) may be adopted in other European regions through EU Soil Mission projects.
- Future funding: Incentivize investments in soil health by financial investment matching (building beyond the Public Private Partnerships principle).

Chapter 4: Research and innovation needs for specific land uses and regional differences: Sustainable Agriculture

4.1 Introduction



Agricultural production systems are the most diverse land use. Due to its diversity in type (intensive and extensive livestock), crop type (arable and perennial) and climatic and socio-economic conditions, the way to promote soil health in all these systems is bound to be different. Healthy soils are essential for sustainable food production, as they support plant growth, regulate water cycles, store carbon, and sustain diverse microbial life. However, intensive farming practices, excessive chemical use, and soil erosion have degraded many European agricultural lands, prompting a shift toward more sustainable solutions. In general, the agricultural sector and society at large in Europe are increasingly aware that maintaining and improving soil health is fundamental to secure food security, biodiversity, and climate resilience. However, the road ahead is still challenging for many actors in the agricultural sector. Ensuring soil health will require a collective effort from policymakers, farmers, researchers, and consumers. Therefore, also soil needs in this land use require a systemic change to increase soil health.

Some key challenges can be identified that are relevant to the successful implementation and sustainability of LLs and LHs: i) land abandonment due to demographic changes in rural areas and changes in the market; ii) adapt to the changing climate; iii) resource management (water, nutrients, organic matter); iv) soil pollution and other soil threats such as soil erosion and compaction; v) biodiversity loss; v) economic pressures and market instability and iv) policy and governance inconsistencies and short-term decisions.

4.2 General Knowledge needs

In this section we highlight the general knowledge needs for agricultural soils across Europe according to our LL knowledge framework that intend to address the challenges above are:

Research and Innovation

- Include the landscape & ecosystem view when studying soil processes and designing regional transformation pathways. For this it is essential to include the relevant parts of the agricultural system: biophysical state and processes (soil, water, biodiversity); social aspects (perception of farmers, acceptance of decision support tools), economic aspects (business models and subsidy streams) and policy and governance aspects (opportunities, synergies and trade-offs of European and national policies).
- Trade-offs: Innovation by the adoption of innovative technologies, may on the one hand increase production by gaining efficiency and on the other lead to compensation of less, but larger scale farmers.
- Research into climate-adaptive crops that require fewer inputs while improving soil quality is necessary for long-term sustainability. this calls for detailed research to analysing the effects of crop types, cropping systems and the combination of management options on soil parameters to optimize climate neutral and sustainable soil management options.

- Develop better and cheaper methods to assess and understand soil biological indicators and processes. For example, to better understand soil microbiomes and their role in soil fertility and carbon sequestration can help develop bio-based soil amendments, such as microbial inoculants, to enhance soil health naturally.
- Synthesize the effects of soil management options in different pedo-climatic conditions across Europe. For example, research into regenerative farming practices—such as cover cropping, agroforestry, and minimal tillage to provide science-based guidelines for farmers to restore soil structure and organic matter.
- Collaboration between researchers, farmers, and technology developers will be key to ensuring that innovations are practical, scalable, and widely adopted across Europe's diverse agricultural landscapes.
- Include socio-economic studies and innovations need to be highlighted, including cultural barriers.

General Co-created innovation

- Understanding the systemic interconnectedness of barriers for sustainable soil management adoption.
- Capacity building for farmers in LLs and LHs to increase soil literacy and knowledge about sustainable soil management. Important awareness needs to be raised carbon flows, the phenomenon of greening and the impact of different types of plant cover on soils are some of the issues raised during the interviews that stakeholders felt would require more in-depth knowledge.
- Co-creation of soil researchers with farmers and farm advisors to develop the matrix of sustainable soil management options under different pedo-climatic conditions. Living labs should allow for such shared work.
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- Establish a network of farmers to foster dialogue between scientists, farmers and other stakeholders in the value chain, enhancing knowledge on soil health and creating incentives for adopting sustainable agricultural soil management practices. This strengthened collaboration will empower farmers to make informed decisions and successfully transition to sustainable farming.
- Co-creation of soil health transition pathways with the whole value chain, as soil health concerns the entire value chain, not only the primary on part of the value chain is responsible for reaching healthy soils in Europe production sectors.

General: MRV and science-based policies

- Link to proposed EU Directive on Soil Monitoring and Resilience to see how farmers can use the opportunities this directive will give. Easy to use and affordable measurement techniques should be available. This side-income will enable further development of LLs.
- Explore further how carbon farming and ecosystem services payments can contribute to the business model of farmers to secure also financial sustainability.
- Innovation in precision agriculture: Developing advanced sensors, satellite imaging, and AI-driven analytics can help monitor soil conditions in real time, allowing for precise application of water, fertilizers, and organic matter.
- Policy-driven research assessing the effectiveness of EU soil protection policies and financial incentives for sustainable farming can guide decision-makers in supporting soil-friendly practices.

- Further develop cost-effective MRV systems that are simple to work with for stakeholders.
- Monitoring effects on carbon content, soil structure, soil biology and nutrient availability of interventions such as post-fire management; agro-foresty, cover crops, the use of mulch in a LL setting.

General Up and out scaling

- Testing and showcasing for outscaling of detailed solutions in LH settings, understanding both the details of the effects certain (nature-based) solutions have on the environment (especially on soil health), economic situation and socio-cultural conditions in the LH and surroundings.
- Business models for LL for sustainable soil management:
    - Multiple income sources in rural areas should be generated and incentivized to avoid overexploitation of soil resources on one side and land abandonment following outmigration on the other side.
- Scaling sustainable soil management:
    - Barriers to upscale (policy, Value chain, societal, financial etc); policy barriers and needs for broad implementation of sustainable land use practices;
- Development and testing of systemic solutions:
    - Further inventories and development on how systemic solutions can be used to overcome barriers for adopting soil-improving practices to enhance soil health and sustainability across varied agricultural contexts. Specific elements to take into account are:
        - Include socio-economic studies and innovations need to be highlighted, including cultural barriers.
        - Regional approach: working towards a regionally based ambitions and solutions and including diverse groups of stakeholders that influence soil management in a multi-stakeholder approach, which will further enabling farmers in the framework of soil health living labs.
        - Increase profitability by securing markets of return on investments or creating new markets such as nature-based solutions and carbon farming, in collaboration with policy actors.
        - Understanding the systemic interconnectedness of barriers for sustainable soil management adoption.

4.3 Specific knowledge needs in North, South. West and East Europe

Introduction

Different regions face unique challenges due to variations in climate, soil types, and agricultural practices. Targeted research and innovation efforts are needed to address region-specific soil management needs in Northern, Southern, Western, and Eastern Europe. In this section we highlight a few of the most important research and innovation gaps that followed from our building blocks (see section ###) that are specific for the four regions of Europe (see figure 2 for the map with the four regions indicated). By addressing region-specific challenges through targeted research and technological advancements, Europe can create resilient, productive, and sustainable agricultural systems that prioritize long-term soil health. Collaboration between scientists, policymakers, and farmers will be key to implementing these innovations effectively.

North

Northern European countries experience cold climates, short growing seasons, and excessive soil moisture, leading to challenges like soil compaction and nutrient leaching. Research is needed to develop **better drainage systems and innovative soil aeration techniques** to prevent waterlogging, soil compaction and loss of soil fertility. Innovation is specifically needed in the area of **precision farming tools**, such as AI-driven nutrient monitoring and controlled-release fertilizers, could help optimize nutrient use. Additionally, studies on **cold-climate suitable cover crops** and regenerative farming techniques can improve and soil structure. In addition to this northern Europe has a lot of peatland where sustainable soil management should be targeted at conserving the organic matter in the soil while still create a viable income for the farmers. Options like **paludiculture and rewetting grasslands** are options to further optimize using new innovations. On the other hand, climate change may pose opportunity in the north for cropping that were previously not feasible.

South

Southern Europe faces severe soil degradation due to drought, desertification, and erosion caused by extreme climatic events and intensive agriculture. Furthermore, the majority of the agricultural land is affected by the use of herbicides and the biological diversity above and below ground is very low. In addition, the increase of intensive agriculture makes it more productive, but causes damages to the ecosystem and social system. Due to climate change the extreme rainfall and droughts will increase in severity and frequency, making problems with salinization, erosion and loss of organic matter even worse. Research should focus on **drought-resistant crops, using mulches such as chipped pruned branches, soil moisture retention techniques, and organic soil enhancers such as biochar and compost.** Innovation in n**ature-based solutions for water, soil and landscape management** should be co-created with a new generation of farmers that will engage to make Mediterranean agriculture healthier. Also, agroforestry (Rodrigo-Comino et al., 2020) and **rewilding strategies** (Cerdà et al., 2018; Kaštovská et al., 2024) should also be explored to combat soil erosion and increase carbon sequestration in degraded landscapes.

West

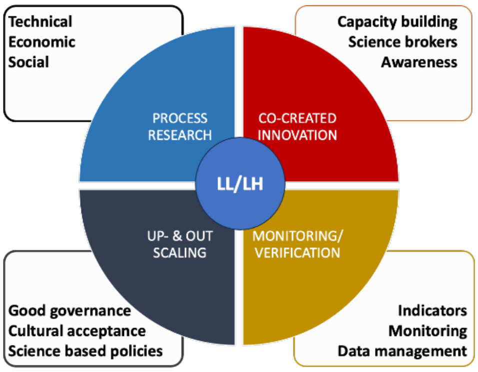
Countries in Western Europe have intensive farming systems that lead to soil degradation, loss of biodiversity, and chemical contamination of both soil and water. Research is needed to enhance s**oil regeneration through reduced tillage, diversified crop rotations, and organic amendments like compost and manure.** Especially, for farms near to nature areas it is important to develop tools to establish LLs that will allow for **extensive or nature inclusive farming** to decrease the environmental pressure on vulnerable nature areas. A more holistic and circular approach to farming, particularly in livestock agriculture, requires an LL approach to implement nature-based methods like agroforestry. Innovation in carbon sequestration techniques, including **carbon farming techniques**, could contribute to soil health and climate goals. Digital soil mapping and decision-making tools could also improve **precision farming**, ensuring optimal soil nutrient management while reducing environmental impact.

East

In eastern European countries intensive farming, overuse of chemical fertilizers and pesticides, and monoculture cropping causes soil pollution, salinization, soil compaction, soil biodiversity decline and organic matter decline. In addition to soil degradation, the agricultural sector suffers from agricultural droughts. Better soil health and **landscape scale nature-based water management** may pose a solution for this. The improvement of water retention at field, farm and landscape scale is one of the key topics to address in the development of knowledge and innovations. In LL setting research focusing on restoring soil fertility through o**rganic farming methods, such as green manures, crop diversification, and microbial soil treatment**s will help to come to a viable agricultural sector. Innovation in land restoration techniques, such as r**egenerative grazing, minimum tillage, secondary crops such as cash and cover crops, intercropping and carbon farming,** could help reverse soil depletion. Additionally, improving education and access to sustainable farming technologies will be crucial for supporting smallholder farmers in adopting better soil management practices.

Chapter 5: Research and innovation needs for specific land uses and regional differences: Sustainable forestry and natural forests

5.1 Introduction



The majority of the earth's terrestrial carbon (C) is stored in the soil with peatlands, grassland soils and forest soils being the largest C sinks with 600, 588 and 372 billion tons (peatland atlas 2023). By effectively absorbing carbon dioxide (CO_2) from the atmosphere and storing carbon in biomass and soil, forests play a key role in both climate-change mitigation and adaptation worldwide (Mo et al. 2023).

More than 40 % of the EU's land area is covered by forests (EEA, 2024). Depending on climate, soil conditions and forest management history, diverse forest types such as boreal evergreen and coniferous forests, temperate deciduous and dryland forests, primary forests and second growth forests/plantations with different carbon sequestration potentials have developed. This should be considered when making ecological and economic judgements.

The demands on forests and associated ecosystem services and economic returns are diverse, not only at national but also at international level. These demands are also evolving due to policy influences and in response to climate change. To responsibly use our forest soils and to lead the transition from damaged to healthy soils would need a long-term management perspective.

Eighty percent of all European forest soils are managed (FISE 2022). According to the new EU Forest Strategy (European Commission 2021c), sustainable forest bio-economy for long-lived wood products and the sustainable use of wood-based resources for bioenergy should be promoted. The protection of primary forests should be strengthened and the re- and afforestation of biodiverse and multifunctional forests should be ensured. Primary forests in the EU only cover 3 % of the land surface but they serve with an exceptionally high and unique biodiversity value. It is important to "leave the dynamic of the forest cycle in these forests as much as possible to natural processes, limiting extractive human activities, while finding synergies with sustainable ecotourism and recreational opportunities" (European Commission, 2021c).

However, the responsibility for the forest policy lies with the member states. National forest programmes address the entire range of issues relating to forests in terms of their multi-functionality and sustainable development: their production function, their protective functions and their contribution to ecosystem services including carbon sequestration and biodiversity, social and cultural aspects (recreation, tourism, rural development). Because information on European forests, forest health and forest soil health was only disseminated at local and regional levels in the past, data was hardly accessible for stakeholders in other countries. Often, forest data is incomplete or outdated. This is a challenge both for carbon accounting and understanding of the ecosystem services expected from forests and forest land.

5.2 Knowledge framework needs

To foster innovation networks for an efficient knowledge transfer-exchange between European and neighbouring countries in general and in LLs and LHs in particular, knowledge framework needs for the health of forested soils (forestry and primary forests/"natural forests") must be evaluated. Data from countrywide monitoring programs on the states and changes of parameters in forests soils could help to draw implications on soil health EU-wide. For improving sustainable food (and fodder &

material) provision and for achieving climate neutrality, the concept of healthy soils is one corner stone of the European Green Deal/EU Strategy for 2030 granting soils the same level of protection as water and air (European Commission 2021c; Panagos et al. 2022).
The following knowledge needs for European forest soils are described according to the LL/LH knowledge framework. Some of the needs are already identified and implemented whereas others must be developed.

Up & Out scaling

Adapt an EU-wide joint soil mission to the different land uses and the specific conditions and demands put on forest systems and soils:
For example, it is difficult to transfer the Knowledge Framework Roadmap Map developed by EJP SOIL (Keesstra et al.,2024) to forest soils, as these are fundamentally inherently different and with different management strategies from arable/agricultural soils. Therefore, social, economic, political and natural control variables for these land uses must be considered separately. In particular, the different rotation periods in agriculture and forestry from 1-3 harvests per year vs. 1 harvest every 12-120 years (depending on pedoclimatic conditions and tree species) must be considered. Consequently, different soil needs must be considered and a Road map approach needs to consider alternative land use, land management and soil conditions. Due to the comparatively long rotation cycle in traditional forestry, tillage (harvesting, reforestation) is often not experienced by the forest owner, whereas a farmer has to think about tillage/soil cultivation several times a year. LLs would be a suitable platform for showing the different scales of land uses in form of exhibitions with display boards and effective short films.
Government calls for research/innovation projects often require cooperation between theory (academia) and practice (e.g. farmer or forester). This serves the mutual gain of knowledge (learning outcome), but also places demands on the e.g. scientist to translate the academic language into generally understandable terms. The practitioner, in turn, must open up to the environment and share the wealth of (everyday) practical experiences. This promotes **co-creation** and synergy effects between all partners as well as up-and-out scaling and leads to reality-based policies. LLs would be a suitable platform for this exchange as workshops could be arranged here.

Co-created innovation

Support multi-stakeholder approaches:
Forest ownership consist of diverse actors, both large scale companies, foundations and private holdings and small holders. In many countries, the owners are organised in some kind of associations (road associations, forest owners, soil or water associations). Through these multi-stakeholder approaches, **capacity building** in terms of **soil related awareness** and **literacy** often is well served. Still in other countries, small forest ownerships and inadequate communication to forest managers often hampers the integration of soil health considerations into forest planning. In many countries, a large proportion of the forest land is state owned. Here, good governance of silviculture between owners (state) and managers (state) should be the everyday order or should be easy to implement. However, EU policies need to consider forest owners of all sizes as key stakeholders in the green transition (Swedish Forest Industries 2024). The social, technical and economic benefits of an exchange on soil-related topics between manifold stakeholders and the transgression of local, regional and national borders would also benefit the direction of a harmonised European roadmap on soil health. LLs would be a suitable platform for multi-stakeholder approaches as workshops and excursions could be arranged here.

Research & Technical Innovation and Monitoring

Enhance quantity and quality of field sampling data for establishing new and improve current models for risk assessment prediction and models for upscaling of e.g. C sinks and sources:

The demand for risk-assessment-prediction-models of biotic and abiotic disturbances in forests is increasing, as ad-hoc changing weather conditions are increasing. Through Research & Technical Innovation combined with high-resolution monitoring data (such as spatial maps), e.g. intelligent early warning systems could better predict threats to the forest. A step into the right direction was done by the establishment of "The Forest Monitoring Information System for Europe (FISE)" to support the EU forest strategy. FISE is the first common database on forest information in Europe providing stakeholders with data of forests from local to EU wide level for future forest policies (FISE 2022). The database includes basic forest data such as forest types, forest land cover, tree cover density, forest above ground biomass and information about forest management, vitality, bio-economy and major pressures such as climate change, forest fragmentation and invasive alien species. Also, the international co-operative programme on assessment and monitoring of air pollution effects on forests (ICP Forest) conducts comprehensive compilation of information on the condition of forests in Europe. From here, information on forest soil conditions can be retrieved. LLs would be suitable showrooms as digital exhibits will attract the interest of the visitors. Here they can press buttons on maps, in the soil profile or in the forest to receive subject-related content.

5.3 Specific regional needs

To cover the different soil types (a variety of mineral soils and peat soils) in the different climates (cold, temperate and subtropical), three case studies for the forest areas were involved in the PREPSOIL regional soil needs assessment. These represent a variety of pedoclimatic and management conditions for forest systems and respective soil management. A typical boreal forest catchment in northern Sweden (with 71,5 % forest cover of the land area) has been chosen as representative case of a managed boreal landscape. Here, young and nutrient-poor soils, such as podsols, gleysols but also histosols and morainic gravel material are the soils for silviculture. A representative case from the northeast of Europe is the Soomaa region in Estonia (with 58,4 % forest cover of the land area) with its forested peatlands. Here, forestry with competing tourism and strict restoration measures as well as old growth forest protection was necessary to be harmonised politically, socio-culturally and with regard to soil health. For the Köprülü Canyon National Park with its old and nutrient-rich soils such as Terra Rossa in the Antalya region in Turkey (with 25,2 % forest cover of the land area), tourism, drought and forest fires impaired the health of the forest soils. From the "mixed" regions in the PREPSOIL regional soil needs assessment, perspectives from Ireland with the lowest forest cover (with 10,5 % of the land area) in the EU and Czech Republic (with 35,6 % forest cover of the land area) were included as well. Afforestation of drained peatlands and forest ownership was considered.
In all cases of this study, climate change was seen as the significant biophysical driver with growing concern in each case study. Higher frequency of severe winds and storms, prolonged periods of droughts and wet weather and more intense rainfalls all contributed to ongoing discussions of the future of the forest and the forest-soil systems at hand. For example higher temperatures can directly contribute to increased pressure of diseases and pests that affect forest vegetation and soil carbon input. This was identified in the Swedish case with recent massive outbreaks of bark beetle leading to the ecological damage of forests with simultaneous economic penalties. Whereas in part a result of a biophysical driver (changing temperatures) the outbreak was enabled by monoculture (socioeconomic driver) forestry, meaning that managed forest landscapes benefit the spruce bark beetle because the forest consists of large areas where all trees are roughly the same size and age. Similar examples can be found in mixed and natural forests, with other diseases occur in forest stands, such as chestnut branch cancer, pine processionary moth, and pine bark beetle as reported from the Turkish case study.
The forest cases in different pedoclimatic conditions dealt with ecosystem services (provisioning, regulating, cultural and supporting) in different ways. Therefore, multiple challenges but also research and innovation needs were identified to address forest soil management forward. Consequently,

future Europe-wide regulations should be better understood as flexible directives adapted to the respective natural and forest systems management options and environment and ”one-size-fits-all forestry policy measures that deliver on all expectations at once should be avoided” (Swedish Forest Industries 2024).

For the successful implementation of regional specific LLs and LHs, the following research needs are listed for the different European regions and Turkey below. Climate change adaption strategies and monitoring of soil data and outreach of results have been seen as main needs in all regions. Enhancing economic incentives in viable business models for multiple actors could help to move back from soil-damaging to soil-conserving management methods.

North

Boreal forests hardly can move away from monoculture forestry as simply any other tree species would be suitable for large-scale production in such climates. Further, forestry on less-developed, nutrient-poor mineral soils and on rocky morainic material is without concurrence to any other land uses here.

- Improve soil damage and compaction risks through refined forest management with soil-conserving measures, which would conserve and increase soil organic carbon stocks and soil structure in mineral soils.
- Improve research on peatland rewetting vs. simultaneous release of toxic metals; questioning timber production on drained peatlands: is wood-biomass sustainable when growing on drained peat still emitting greenhouse gases?
- Improve pest and disease control measures to enhance C sequestration in forest vegetation and in forest soils.
- More studies on the forest composition and on other forest management methods besides rotation-management are needed.

Southeast

- Increase public awareness on soil health, soil literacy, co-created innovation processes and stakeholder involvement.
- Improve tourist infrastructure for avoiding forest fragmentation, soil erosion and desertification.

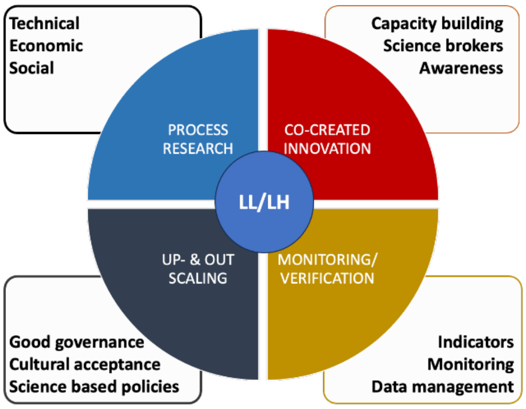
West

- Improve peatland rewetting for climate mitigation and for reducing soil pollution and enhancing restoration as well as for conserving and increasing soil organic carbon stocks and soil structure in organic soils.
- Improve subsidies and long-term payment for forest owners while at the same time questioning afforestation of drained peatlands: is wood-biomass sustainable when growing on drained peat still emitting greenhouse gases?
- Provide training for conservation actions, which would increase soil literacy, co-created innovation processes and stakeholder involvement.

East

- Increase soil literacy, co-created innovation processes and stakeholder involvement.
- Change from monoculture- to mixed-culture forestry to decrease bark beetle infestation and financial penalties.
- Improve soil damage and compaction through refined forest management with soil-conserving measures, which would increase soil structure to enhance soil biodiversity.
- Improve tourist infrastructure for avoiding forest fragmentation and soil erosion.

Chapter 6: Research and innovation needs for specific land uses and regional differences: Soils in urban/industrial areas



6.1 Introduction

Urban areas are unique because they contain many different land uses within the built-up area; each with individual soil needs. On the one hand, urban soil is needed for delivering ecosystem services, like climate regulation, and it is the basis for greens in parks, gardens, green infrastructures etc. From this perspective, it is of importance that the soil is unsealed and unpolluted. On the other hand, the subsurface is used in urban areas as the basis for building activities or as space for cables and pipes. Here, the carrying capacity is of importance. Further, in urban areas there are many different landowners and stakeholders, both public and private, with their own agendas and priorities, which makes it difficult to steer towards soil health.

For both **urban and industrial** areas the chemical soil quality is one of the longest studied and most well-known issues related to soil health. In urban and (post)industrial areas, where remediation or regeneration / redevelopment takes place, opportunities arise to improve soil health and use the soil water system within spatial planning and design to achieve a more resilient link between the land use and the natural system.

In **mining areas**, the landscape is impacted a lot by the mining activities. Contamination and instability of the subsoil make it challenging to find a suitable future and beneficial (to human and/or nature) use in which soil health is improved.

Within the PREPSOIL regional soil needs assessment, three case studies were available for urban and industrial land uses. Two of these related to post-mining areas in Poland and Slovenia (both Eastern Europe) and one focused on an urban area in the Netherlands (Westen Europe).

With this basis, it is hard to differentiate between the North, East, South and West. To complement the soil needs assessment data, R&I needs defined in the SMS project (Ittner et al, 2022) where identified and a multi-scale survey of examples including 1) projects, 2) programmes, and 3) environmental laws was done across the four regions. Projects include LLs and LHs found on the PREPSOIL website[1]. Programmes include city or country level programmes initiated by governments. Environmental laws include national laws aligned with the EU soil mission.

6.2 Knowledge framework needs

With reference to the knowledge framework introduced in this report, **monitoring** stood out as a common knowledge need across all regions. This includes the need for better data management, the need to quantify the empirical capacities delivered by soil-based measures to address climate change and the need for improved data availability (findability, accessibility, interoperability, and reusability (FAIR)). Not all countries have a soil monitoring system, and in those with a soil monitoring system, not all countries make their data available to third parties.

Not all countries in the EU have effective legislation on soil contamination of other environmental topics. Further, due to the complexity and fragmentation of urban soils, a clear and uniform definition of what urban soil health is, is needed. These are barriers in the **up and out scaling** quadrant of the framework.

Specific **research & innovation** needs that are of importance for urban and (post)industrial land as defined in the SMS project (Ittner et al, 2022) are:

- The development of instruments to avoid soil sealing, by:
    - identifying indicators to monitor soil sealing and land take processes and their impact. *Monitoring & verification*
    - giving guidance for avoiding soil sealing and reusing land and soil and conserving soil functions. *Up & outscaling*
    - raising awareness of the benefits and values of unsealed soils and urban green and blue infrastructure and nature-based solutions. *Co-created innovation*
    - developing policies and assessment/support tools at municipal level to reduce soil sealing. *Up & outscaling*
    - Limiting soil sealing through responsible planning and smart densification. *Up & outscaling*
- Improving knowledge to avoid and remediate soils from pollution, by:
    - improving knowledge of the fate and impact of (combined) pollutants. *Process research*
    - developing cost-effective methods for the mapping and monitoring of pollution. *Monitoring & verification*
    - stimulating knowledge exchange and capacity building on measures to avoid soil pollution. *Co-created innovation*
    - defining targets and incentives to start restoration. *Up & out scaling*

6.3 Regional needs

Many R&I needs are valid for all urban and industrial areas, regardless of location, however, there are certain important aspects to consider when setting up urban or industrial LL s which vary across Europe:

- Climate and landscape: these aspects determine the occurrence and severity of soil threats (e.g. temperature, precipitation, extreme weather events, kind of soil, slopes, etc)
- Demography and Socio-economic situation: urbanisation rate, population growth, but this also determines the easiness to redevelop impacted land (e.g. former industrial sites), is the pressure on space high enough to make this beneficial, is there enough budget in place?
- Environmental Legislation and policies in place? Not all countries in the EU have effective legislation e.g. on contamination and or other environmental topics
- Data availability (findability, accessibility, interoperability, and reusability (FAIR)). Not all countries have a soil monitoring system. In not all countries monitored data is available for third parties.

Below, the knowledge needs that are specific to one of the four analysed regions are highlighted.

North

In Northen Europe where countries experience cold climates, freezing temperatures can impact soil stability and permeability. Therefore, for these regions, research is needed on managing urban soil sealing and compaction, particularly in cities with limited green space.

East

There is a significant gap in urban soil health research and projects, with little focus on sustainable land use transitions. Key research needs in Eastern Europe include addressing soil contamination from past industrial activities, improving soil monitoring systems, and developing frameworks for integrating soil health into urban planning. It was also found that additional **research** is needed on urban soils in Eastern Europe. There are currently no known urban projects or programmes around urban soil health. Along with this, soil monitoring processes and data availability should be improved and harmonized.

South

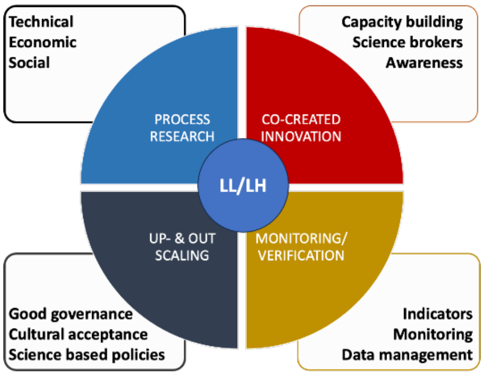
In Southern Europe, the main challenge is soil degradation due to heat stress, droughts, and water scarcity. Additional research is needed on the role of urban soils in water retention and climate adaptation, as well as best practices for managing green (and blue) urban infrastructure to counteract desertification and urban heat islands.

West

While there are more established policies and programmes in Western Europe that focus on urban and industrial soil health, challenges still remain with regards to policy implementation, soil pollution from historical urbanization, and balancing urban densification with soil conservation. There is a need for better integration of soil health within city planning and further innovation in reducing soil sealing.

Chapter 7: Research and innovation needs for specific land uses and regional differences: Changing/ interfaces of different land uses

7.1 Introduction



Land use has always changed over time. The change has an effect on the soil, it can be beneficial or degradational for the soils. In this section we discuss the drivers and effects of soils that were under agriculture and change to urban land use; soils that were under nature and are under pressure from tourism and soils that were under agriculture and are now abandoned. Next to these changing land uses there are also land uses that combine two traditional land use types, such as agroforestry and peri-urban areas. We will discuss the benefits and trade-offs of such systems. As specific types of drivers and connected changing land uses are specific for regions in Europe, this section highlights the research and innovation needs per land use interface.

7.2 Agriculture-nature/forestry interface

The interface of agriculture and nature or forestry comprises of three different types: i) land abandonment (from agriculture to nature); ii) rewetting of drained and degraded peatland (from agriculture to nature); iii) increased pressure of tourism on nature.

7.2.1 Land abandonment (mainly South and East Europe)

Drivers and effects on soils

Land abandonment is a growing issue across Europe, particularly in south and eastern Europe, driven by economic, social, and environmental factors. One major reason is **rural depopulation**, as younger generations migrate to urban areas in search of better job opportunities, leaving agricultural land untended. Additionally, **low agricultural profitability**—due to high production costs, price volatility, and competition from global markets—discourages farmers from maintaining their land. **Climate change and extreme weather events**, such as droughts, soil erosion, and wildfires, make farming increasingly difficult in certain regions, particularly in Southern and Eastern Europe. Furthermore, **EU agricultural policies and subsidies** sometimes favour large-scale industrial farming, making it harder for smallholder farmers to sustain their livelihoods.

The impact of land abandonment on soils varies depending on how the land is left to regenerate. In some cases, abandoned land allows for **natural soil recovery**, improving organic matter and biodiversity as vegetation returns. However, in many cases, **soil degradation worsens**, as neglected land becomes prone to erosion, desertification, and invasive plant species. Without reflective and active management, **soil compaction, nutrient loss, and decreased microbial diversity** can reduce the land's potential for future agricultural use.

Research and innovation needs

To mitigate these effects research and innovation is needed to:

- Restore abandoned lands through **regenerative agriculture, reforestation, and landscape management** *(Co-created innovation)*.

- **Implement a clear renaturing plan that allows** the area to be used for nature, but without negative consequences like erosion, pests and invasive species colonization (*Up & outscaling)*.
- Conducting studies on **natural soil recovery, carbon sequestration, and biodiversity restoration can guide policies that can promote sustainable land and water management (***Process research)***.**
- Using research to guide policies that promote sustainable land and water management preventing or reverting land abandonment (*Up & outscaling)***.**
- Assess the socio-economic drivers of the land abandonment to understanding the drivers will make it possible to revive rural communities and sustainably recover rural communities *(Process research)*.
- Develop innovative land-use models, precision monitoring technologies, and incentives for sustainable re-cultivation or conservation are essential to address land abandonment challenges *(Monitoring &verification)*.
- Promote the establishment of Living labs as key tools for building thriving rural communities *(Co-created innovation)*.

7.2.2 Rewetting peatlands

Drivers and effects on peat soils

Peatlands (organic soils) can be found all over Europe with their main concentration in northern, eastern and western Europe. To increase food, fodder and timber production, many peatlands were intensively drained for agriculture, forestry, and peat extraction since the 18th century. Drainage leads to peat shrinkage through oxidation with simultaneously carbon loss mainly in form of CO_2 emissions., and habitat destruction. Peatland restoration is essential for achieving climate targets. When active peatland use is terminated (e.g. concession for peat extraction ended; peat is reaching the mineral soil), peatland after-use is obligatory in most countries. Restoration could be one option for an after-use measure. To restore the ecosystem services peatlands can give, rewetting is gaining priority across Europe due to its crucial role in climate change mitigation, biodiversity conservation, improving water retention to reduce floods and agricultural droughts, and filtering pollutants.
Rewetting peatlands reduces or even halts peat decomposition, preserving organic matter and stabilizing carbon storage. When fully rewetted, carbon can be stored again by peat forming vegetation such as *Sphagnum spp.* or *Phragmites australis*. The amount of methane emissions that result from rewetted conditions can compromise the climate benefit somewhat, but do not fully nullify the positive effect of carbon sequestration. Moreover, other benefits like biodiversity recovery, and improved water quality, make peatland restoration a key strategy for sustainable land management in European peatland regions.

Research and innovation needs

To enhance quantity and quality of peatland restoration, research and innovation is needed to:

- Map drained peatlands suitable for rewetting and to monitor adjacent areas which should not be hampered by rewetting *(Monitoring & Verification)*. Much knowledge is available from rewetting of former peat extraction sites. Rewetting of drained peatlands used for forestry and agriculture is less developed and should only be done by the evaluation of the physico-chemical peat conditions and a risk assessment analysis before the measure. Unreflective rewetting would jeopardise other sustainable development goals such as “No eutrophication” and would lead to expansive countersteer mechanism in the future (*Awareness; social & technical Process research*).

- Find new, climate-smart and sustainable land uses such as **paludiculture (wetland agriculture)** to enhance both the natural environment as well as the local and viable value chain.
- Developing **economic incentives and policies** for peatland conservation is crucial for large-scale restoration across Europe while at the same time developing **economic incentives and policies for farmers and foresters** to take the drained peatlands out of conventional use and to start paludiculture (*Co-created innovation; Up & Outscaling*).
- Depopulated regions with degraded peatlands can be revitalized through making the region attractive for carbon farming and tourism. Such **place-based and systemic approaches** in which the two land uses (agriculture and nature) are combined are essential for setting up new LLs in peatland areas.
- Balance the carbon sink potential of a forest against the carbon sink potential of a growing peatland and avoid forestry on drained peatlands (*Process research*).

7.3 Tourism pressure on nature (across Europe, especially in South and Alpine area)

Drivers and effects on soils

Touristic regions in both alpine and coastal environments face unique soil health challenges due to high visitor foot traffic, infrastructure development, climate change, and unsustainable land management. These pressures lead to soil erosion, degradation, pollution, and loss of biodiversity. Addressing these issues requires targeted research and innovative solutions to ensure long-term soil sustainability in these ecologically sensitive areas. The largest problems occur in the Alpine areas and in coastal areas with mass-tourism. Alpine regions are highly vulnerable to soil degradation due to steep slopes, harsh climatic conditions, and seasonal tourism. Pressure due to hiking and skiing causes soil erosion, compaction and organic matter loss; which in turn leads to flooding and shallow landslides. Inn coastal areas soil degradation due to tourism-related development cause several problems: i) saltwater intrusion and with that soil salinization; coastal construction and beach tourism cause soil sealing, soil pollution and disrupt natural ecosystems as well as severe pollution due to waste disposal and overuse of chemicals.

Research and Innovation Needs

To reduce the pressure of tourism on European soils the following research and innovation needs can be identified:

- Test and use Nature-Based solutions in a LL approach *(Co-created innovation and Up & outscaling).*
- Test and implement strategies in tourist areas to reduce pollution, replant native species, and apply bioengineering techniques (e.g., geotextiles, vegetated retaining walls) (*Process research* and *Up & outscaling)*.
- Innovate eco-friendly ski resorts and hiking trails to minimize soil erosion and compaction *(Research&Innivation; Up&outscaling).*
- Focus on effect monitoring to assess the co-benefits of sustainable eco- and agro-tourism, including circular economy strategies *(Monitoring &verification).*
- Develop spatial planning solutions (e.g., dune restoration) to support long-term sustainability (*Process research* and *Up & outscaling).*
- Advance region-specific research and technology for soil sustainability and economic viability in alpine and coastal tourist areas *(co-created innovation and Up&outscaling)*.

- Test and integrate erosion control, climate adaptation strategies, and sustainable tourism management, and spatial planning where soil and water resources are considered these landscapes can be preserved for future generations. *(process research and up&outscaling).*

7.4 Peri-Uban areas

Introduction

Peri-urban areas—zones at the interface of urban and rural landscapes—play a crucial role in sustainable food production, biodiversity conservation, and climate resilience.

Drivers and effects on soils

Soil health in peri-urban regions is often compromised due to urban expansion, soil contamination, soil sealing, and intensive land use. The occurrence and severity of these challenges varies across Europe. **Urban expansion** in which housing and infrastructure tend to be prioritized over agricultural land and nature areas play a big role in highly urbanized and rapidly expanding cities in **Western and Northern** Europe like Amsterdam. **Soil contamination** due to former industrial sites plays a notable role in countries like Poland and Slovenia in **Eastern Europe**. Here, improper land management in peri-urban areas and deforestation also contribute to soil erosion. In **Southern European** regions like Spain, peri-urban areas are at risk of soil degradation and desertification due to intensive agricultural land use, and severe drought conditions accelerate due to climate change.

Research and Innovation Needs

In peri-urban areas, research and innovation tailored to the specific challenges in Northern, Southern, Western, and Eastern Europe are essential to restoring and maintaining peri-urban soil health. Given the diverse regional challenges across Europe, research and innovation needs should be tailored to local conditions.

- Test and implement sustainable land use planning solutions, including green infrastructure and de-sealing initiatives, to address soil health challenges in Western and Northern Europe *(Process research, Up & outscaling, Co-created innovation*).
- Prioritize the development and application of soil remediation technologies and reforestation practices to enhance soil quality and combat degradation in Eastern Europe (*Process research, Up & outscaling)*.
- Focus on the adoption of climate-resilient agricultural practices, along with water retention strategies and soil regeneration techniques, to improve soil health in Southern Europe (*Process research, Up & outscaling*).
- Monitor and assess the effectiveness of soil health restoration initiatives, ensuring continuous improvement and long-term sustainability of soil in peri-urban landscapes (*Monitoring & Verification*).

Chapter 8: Barriers and opportunities for sustainable soil management on regional scale using Living Labs and Lighthouses

8.1 Introduction

This regional research and innovation agenda for soil health focuses on co-created innovation, experimentation, and scaling of sustainable soil management practices in Living Labs and Lighthouses. By continuous involvement of multiple stakeholders and continuously adapting the implementation strategies based on local conditions, this approach can significantly improve soil health, enhance climate resilience, and contribute to sustainable agriculture and ecosystem restoration at the regional level.

There are barriers identified to start a Living Lab. And also, different projects have identified barriers for implementing results (practices to promote sustainable soil management) from a project or Living Lab setting into the real world. These barriers can be financial, technical, institutional, policy-related, cultural/social. Also soil literacy is of importance. The awareness on the matter drives decision making and the willingness to change. Below these barriers and potential solutions are illustrated, first the barriers for starting the cocreation in a LL setting, then the barriers for implementing practices to improve soil health by sustainable soil management.

8.2 Financial barriers and opportunities for Living Labs and Light Houses design and implementation

Financial barriers for the establishment of Living Labs and Lighthouses include high initial investment costs, uncertain long-term funding (while soil processes are slow), and limited private sector engagement. Many projects rely on public grants, which may be short-term and bureaucratically complex. Additionally, lack of financial incentives for stakeholders can hinder participation.

However, there are opportunities through EU funding programs (e.g., Horizon Europe) specifically the calls for LLs within the soil mission and the support given by the SOILL project to starting LLs. However, due to the large interest in this funding tool, the lengthy and uncertain process can also be a barrier for starting a LL. Another opportunity is public-private partnerships, that not only drive scientific discovery but also promote economic growth and societal benefits. To stimulate PPPs it is recommended to generate a list of innovations and insights on practices in specific pedo-climate zones as a door-opener for the private sector and explore pre-competitive investment options to increase the TRL level of the practices in collaboration with the farmer and farmer advisors' sector.

Another opportunity is the facilitation of impact investments supporting sustainability and innovation, where large industries invest in innovations to generate measurable environmental benefits. Increasing the profitability by securing markets of return on investments or creating new markets such as nature-based solutions and carbon farming and co-financing models can help to attract funding, in collaboration with policy actors. Developing business models with revenue streams, such as knowledge transfer services or sustainable product commercialization, can enhance financial viability for long-term success.

In terms of financial barriers, the uncertainty on 'return on investment' is in different fields a clear barrier to start a LL or change the way of working Table 1).

Table 1, examples of financial barriers for implementing results (practices to promote sustainable soil management) from a project or Living Lab setting into the real world ([1] Hagemann et al., 2019, [2] Maring et al., 2019, [3] Maring (ed.), 2024)

Objective:	Barriers

to implement SSM by farmers[1]	• Investment uncertainties (e.g. when changing farming systems) • Lack of equipment and investment capital • Additional costs (e.g. for labour or new machinery)
to consider soil quality in spatial planning[2]	• Inadequate financial arrangement, • Division costs and benefits to different actors or moments
to reuse contaminated land and soils[3]	• incoherent financial framework (lack of national financial commitment in land decontamination); • underestimation of the long-term maintenance costs; • insufficient financing, no interested investors or lack of resources, due to lack of incentive; • potentially substantial capital costs for remediation and regeneration; • compared to greenfield redevelopment, brownfield redevelopment involves high level of uncertainty and financial risks; unsupportive tax policy (i.e., developers of brownfield properties pay higher tax compared to greenfield developers); • cost of land remediation and regeneration exceeds the benefits of the project. • negative values in books

8.3 Technical barriers and opportunities for Living Labs and Light Houses design and implementation

Technical barriers include data integration challenges, as diverse monitoring systems lack standardization, and scalability issues, where solutions tested in pilots may not work across regions. Infrastructure limitations in rural areas hinder digital adoption. Knowledge gaps in digital transitions, such as Artificial Intelligence (AI), Internet of Things (IoT), and innovation opportunities, such as precision farming, or the integration of soil health in spatial planning and design concepts, hinder the implementation in Living Labs.

However, opportunities exist through advanced sensing and AI-driven analytics for real-time monitoring, digital twin models for predictive decision-making, and interoperable open-source platforms for knowledge sharing. Automation and robotics improve efficiency, while nature-based solutions (e.g., agroforestry, biochar) enhance resilience, making Living Labs and Lighthouses impactful. Table 2 shows several technical barriers for the communities involved in land management to change their way of working. In most cases it is a lack of access to knowledge.

Table 2: examples of technical barriers for implementing results (practices to promote sustainable soil management) from a project or Living Lab setting into the real world ([1] Hagemann et al., 2019, [2] Maring et al., 2019, [3] Maring (ed.), 2024)

Objective:	**Barriers**
to implement SSM by farmers[1]	• Lack of knowledge (e.g. how to use the equipment and implement measures)
to consider soil quality in spatial planning[2]	• Insufficient (availability of) data and tools
to reuse contaminated land and soils[3]	• lack of locally available expertise and fragmented visualization of perspectives of the problem • uncertainty during the planning process due to unknown or unexpected contamination level; • unavailability of data about the contaminated land

	• site geology and contamination level are complex (e.g., emerging contaminants, multiple contamination etc) and make it difficult to assess potential risk

8.4 Institutional/administrative barriers and opportunities for Living Labs and Light Houses design and implementation

Institutional and administrative barriers include bureaucratic complexity, were rigid regulations and lengthy approval processes delay project implementation (Table 3). Fragmented governance across local, national, and EU levels creates inconsistencies, making cross-border collaboration challenging. Lack of dedicated funding mechanisms (beyond the Mission Soil project support) and unclear institutional responsibilities may challenge long-term sustainability for LLs. However, options for institutionalizing a LL exist, which may ensure a professionalization of the governance and resource acquisition to allow a stronger financial and participatory set-up. This includes conscious actions to mature a LL by developing its Business Model (using e.g. the business model canvass as part of a LL service package developed by the Prepsoil project: Business Model Canvas for Living Labs & Lighthouses in the Mission Soil | Prepsoil . Other opportunities lie in the engagement of value chain actors (businesses such as input providers, processors, …) in the governance as well as supporting co-creation and uptake. Moreover, the idea of engaging local/regional policy makers/civil servants as stakeholders in LLs may in principle allow for a science-policy-society interface, which could overcome barriers linked to legal and public administration (see also Prepsoil D1.6 (submitted but not yet approved) on science advice in LLs). To what extent LLs will in fact succeed in engaging civil servants in dialogues is an open question, which could be subject to socio-economic studies as part of the SRIA.

Additionally, limited coordination between research institutions, policymakers, and practitioners may reduce efficiency in knowledge transfer. However, a main idea of the Mission soil LLs is to strengthen the AKIS (agricultural knowledge and innovation system) and use lighthouses and learning processes (open field days, training courses, peer groups for knowledge exchange, ..) to ensure dissemination and exploitation of the results of co-creation experiments. Prepsoil D6.2 (Synthesis of training needs and co-learning strategies for AKIS in soil health (submitted but not yet approved)) presents results from interview-based studies of the potential in integration of "farmers' experience-based knowledge and the advisors' research-based knowledge" in different exploitation activities such as demonstration farms and workshops. The study suggests that the concept of Lighthouses (demonstration farms) may be a suitable tool for this knowledge exchange if the co-creation activities lead to "trustworthy and unbiased knowledge in relation to soil health that is applicable to region relevant challenges". Thus, there are ways – and some experiences in different European countries – of improving efficiency in knowledge transfer.

However, opportunities exist through streamlined regulatory frameworks, fostering innovation-friendly environments. Stronger multi-level governance can improve coordination, while EU programs like Horizon Europe offer (often 4 year) funding support. Public-private partnerships and digital governance tools can enhance administrative efficiency, ensuring Living Labs and Lighthouses drive sustainable transformation. Simplified procedures and institutional alignment will accelerate implementation.

Table 3: Examples of institutional barriers for implementing results (practices to promote sustainable soil management) from a project or Living Lab setting into the real world ([1] Hagemann et al., 2019, [2] Maring et al., 2019, [3] Maring (ed.), 2024)

Objective:	Barriers

to implement SSM by farmers[1]	• Lack of support (e.g. in form of advice from administration) • High transaction costs (e.g. for the implementation of measures in terms of field monitoring) • Measure design conflicting with SSM
to consider soil quality in spatial planning[2]	• No awareness on the topic, continue traditional practice
to reuse contaminated land and soils[3]	• lack of clear lead-responsible stakeholders or not wanting to take responsibility which usually leads to postponing the situation; • perception that such development is a private sector issue • the involvement of many stakeholders (including landowners) creates complexity in remediation thus making it difficult to see possible end-results; • lack of incentives for brownfield redevelopment;

8.5 Policy barriers and opportunities in Living Labs and Light Houses design and implementation

Legal and policy barriers include fragmented regulations across EU and national levels, slowing implementation of LLs and LHs (Table 4). Complex permitting processes delay innovative solutions, or sometimes legislation simply prohibits implementation of certain innovations or solutions. Short-term policy and funding cycles create uncertainty for long-term projects, which often are necessary to observe soil health improvements from changed management practices. Limited or adverse financial incentives and bureaucratic hurdles also discourage stakeholder participation in LLs.

However, opportunities exist through EU Green Deal strategies, Horizon Europe funding, and Common Agricultural Policy (CAP) incentives supporting sustainable innovation. Harmonized regulations can facilitate cross-border collaboration, while public-private partnerships enhance implementation. Policies promoting open data, ecosystem-based approaches, and climate adaptation can strengthen Living Labs and Lighthouses as drivers of sustainable transformation. Moreover, the development of the EU Soil Monitoring Law – if finally endorsed by EP and the council – may create awareness in MS of the necessity of a regional approach to focus on the most pertinent Soil Health challenges. This may motivate elected politicians and civil servants at regional and local/municipal levels to engage in Living Labs and Lighthouses to support co-creation of improved soil health management. The idea of LLs includes engaging a quadruple helix of stakeholders including policy makers. LLs this way offer a unique opportunity for reinforcing science-policy interfaces and science-policy-societal interfaces (Keerthi et al., 2025, D1.6). These interfaces can contribute evidence and knowledge for designing policies supporting healthy soil management at field, farm and value chain level in an agri-food systems approach with focus on policy coherence. As mentioned above this is mostly a hypothesis and time will show to what extent policy makers/civil servants will prioritize participation in LL activities. Prepsoil contributed to a workshop in experiences of science-policy interfaces in LLs (Ghent group, November 2024). The case studies presented examples of successful science-policy interactions, which required sufficient time, flexibility and willingness to adapt the approaches and with positive roles of so-called knowledge brokers and social scientists (Prepsoil D1.6).

Table 4: examples of policy and legal barriers and opportunities for implementing results (practices to promote sustainable soil management) from a project or Living Lab setting into the real world ([1] Hagemann et al., 2019, [2] Maring et al., 2019, [3] Maring (ed.), 2024), Prepsoil D1.6

Objective:	**Barriers / opportunities**

to implement SSM by farmers[1]	• Other policies conflicting with SSM Input to policy reforms (CAP, ecoschemes, ..) in S-P-S Interface via LL.
to consider soil quality in spatial planning[2]	• No law, policy, regulation and/or institutions Evidence from Soil Needs assessment and LLs to regional spatial policies
to reuse contaminated land and soils[3]	• incoherent and weak institutional and legal frameworks (i.e., lack of clear and realistic policies for land remediation and regeneration) which creates complexity and uncertainties for investors; • lack of policy supports for innovation; • absence of consistent redevelopment frameworks and/or identifiable and consistent clean-up standards Soil monitoring law requiring implementation of monitoring program and – subsequently – plans for remediation and improved soil management

8.6 Cultural and social barriers and opportunities for Living Labs and Light Houses design and implementation

Cultural and social barriers include resistance to change, e.g. traditional farming communities may be skeptical of new technologies. Lack of stakeholder engagement and low awareness of Living Labs and Lighthouses limit adoption. Knowledge gaps and unequal access to innovation create disparities, particularly in rural areas. Also, lack of communication, collaboration, information and knowledge exchange between different actors can hinder the setup of LLs and uptake of sustainable soil management measures and strategies (table 5).
However, opportunities exist through participatory approaches that involve local communities in co-creation, fostering trust and knowledge exchange. Education and training programs can bridge skill gaps, while social innovation networks and multi-stakeholder collaboration enhance acceptance. Promoting regional identity and sustainable traditions can help integrate Living Labs into local cultural landscapes.

Table 5, examples of policy and legal barriers for implementing results (practices to promote sustainable soil management) from a project or Living Lab setting into the real world ([1] Hagemann et al., 2019, [2] Maring et al., 2019, [3] Maring (ed.), 2024)

Objective:	**Barriers**
to implement SSM by farmers[1]	• Mental models of society and other farmers (→ prohibiting changes in farming practices) • Demographic factors (e.g. different interests between old and new generations, farm succession) • Self-image and life satisfaction of farmers
to consider soil quality in spatial planning[2]	• Lacking communication and collaboration, • lacking information and knowledge exchange
to reuse contaminated land and soils[3]	• lack of communication amongst stakeholders, towards the community and investors and / or about the significance of the project or the risk of not remediating • lack of interest, thus no urge to anticipate on cessation of use (i.e., lacking sense of urgency); • public opposition and negative perception and acceptability of re-using BF land;

	• the site is located within / close to community heritage, and may increase resistance to redevelopment, particularly when these areas hold cultural / generation significance for the community • fear that remediation causes nuisance for neighbourhood (e.g., air pollution, noise)

8.7 Soil literacy needs

Stakeholders need to be aware of the benefits of improving soil health before they change their attitude, behaviour and ways of doing things. These can be financial benefits, but also social or environmental. Awareness about the impact of their choices on other areas, other land uses and next generations is crucial, to support transparent decision making.

Soil literacy is a critical component of sustainable soil management, influencing how stakeholders perceive, interact with, and ultimately protect this essential resource. The **Mission Soil initiative** has identified a lack of soil knowledge and awareness as a major obstacle to improving soil health. Many stakeholders—including farmers, landowners, policymakers, industry actors, and the general public—often underestimate the importance of soil in relation to food production, climate regulation, biodiversity, and water management. Without a clear understanding of how soil functions and the benefits of maintaining its health, there is little motivation to change behaviors or adopt sustainable management practices.

Developing soil literacy is not merely an educational objective; it is an essential step toward ensuring effective land stewardship and long-term resilience. Within the **STRIA PREPSOIL Plan**, soil literacy plays a crucial role in supporting the creation and scaling of **Living Labs (LLs) and Lighthouses (LHs)**, which act as platforms for testing, demonstrating, and applying soil management strategies. By embedding soil literacy within **governance structures, financial frameworks, and public engagement initiatives**, stakeholders at multiple levels can be equipped with the knowledge necessary to take informed decisions that contribute to soil sustainability.

Addressing the gap between scientific knowledge and real-world soil management requires a **multi-dimensional approach** that integrates education, policy, economic incentives, and practical training. Soil literacy must be developed across multiple levels, from school education to technical training for farmers and land managers, from public awareness campaigns to science-policy dialogues. **EJP SOIL stakeholder assessments and PREPSOIL project findings** emphasize that the most effective approaches to soil literacy involve hands-on, interdisciplinary, and problem-solving methodologies that encourage participation and active learning. Education initiatives must be tailored to different land-use contexts and socio-economic conditions, ensuring that soil knowledge is not only available but also applicable.

In a survey done in PREPSOIL (D6.2) a quantitative online study conducted in seven EU countries (Denmark, France, Germany, Netherlands, Poland, Spain and Sweden) to assess the regional differences of soil health awareness among professionals that are seen as key actors for supporting change towards more soil health friendly practices within agricultural, forest and urban land uses. The survey results showed that that there were rather large differences both between countries and land use types to what extent they agreed with the problem description regarding soil health as put forward in Mission Soil.

The surveys pinpointed lack of awareness/knowledge and lack of governance as two hindrances for improved soil health, both across land use types and countries. The lack of national/regional clarity how to integrate the Mission Soil ambition in different land uses in different countries/regions, most likely also affect the willingness and possibilities to participate in competence development in soil health relevant topics. In all surveys, "the soil health concept in general", "how to assess soil health" and "management strategies to improve soil health" were topics that were ranked high as prioritized topics to learn more about. The preferred format for such competence development measures, were often a combination of digital events and field visits – thus a combination of learning in both theory and practice.

One of the key challenges in enhancing soil literacy is ensuring that it translates into tangible behavioral change. Awareness alone is not enough; it must lead to action. Several barriers hinder the adoption of sustainable soil management, including **economic constraints, policy misalignment, resistance to change, and limited access to practical decision-support tools**. Farmers and landowners, for example, may recognize the benefits of improving soil health but face financial challenges in transitioning to regenerative practices. Similarly, policymakers may support the integration of soil health into environmental and agricultural policies but lack the technical expertise to implement effective soil monitoring and governance strategies. Overcoming these challenges requires a combination of **education, incentives, and participatory engagement mechanisms** that facilitate knowledge exchange and co-creation of solutions.

Strengthening soil literacy has significant economic and policy implications. A better understanding of soil health can unlock financial opportunities for farmers and land managers, such as **payments for ecosystem services, carbon farming credits, and access to EU Green Deal funding**. Improved soil knowledge also allows for better land-use planning, enabling decision-makers to integrate soil health into biodiversity conservation, climate adaptation, and water management strategies. In the governance sector, policymakers equipped with soil literacy tools are more likely to develop regulations that are evidence-based, practical, and aligned with long-term sustainability goals. Moreover, soil literacy can enhance cross-sector collaboration, ensuring that soil health considerations are embedded across different policy areas rather than treated as isolated agricultural or environmental issues.

Living Labs and Lighthouses provide an innovative pathway for strengthening soil literacy by offering real-world environments where knowledge can be tested, shared, and refined. These spaces facilitate interactions between farmers, researchers, policymakers, and industry actors, enabling them to experiment with new techniques and scale effective soil solutions. Through interactive workshops, data-sharing platforms, and peer-to-peer learning networks, LLs and LHs serve as **centers for applied soil education**, bridging the gap between research and practice. They also provide an opportunity to engage local communities, promoting a shared responsibility for soil conservation efforts.

Beyond the agricultural and policymaking sectors, enhancing public awareness of soil health is essential to fostering a culture of environmental stewardship. Engaging the wider public in soil literacy initiatives can be achieved through **citizen science projects, educational campaigns, and urban sustainability programs**. These initiatives encourage individuals to recognize the broader implications of soil degradation and become active participants in conservation efforts. Soil literacy is also crucial for climate resilience, as healthy soils play a key role in **carbon sequestration, water retention, and biodiversity support**. Societies that are better informed about soil's role in mitigating climate change and ensuring food security will be more inclined to support policies and practices that protect soil resources.

Ultimately, soil literacy is not just about acquiring knowledge—it is about creating a shift in mindset that leads to sustainable decision-making at all levels of society. By investing in education, governance, and financial mechanisms that promote soil awareness and engagement, Europe can accelerate progress toward the **Mission Soil objectives**. A soil-literate society is one that understands the value of soil, integrates it into economic and policy frameworks, and actively works to protect it for future generations.

Chapter 9. A future outlook: advancing good practices.

In this region-focussed research and innovation agenda we provide guidance for research an innovation to support the development of new Soil Health LLs across Europe, which is the main aim of the Mission Soil. In this chapter some key requirements towards the enabling conditions for using the recommended pathways in this agenda are highlighted. that are seen as key to lead the transitional change needed to adapt to climate change and socio-economic changes across Europe.

9.1 Long-term funding strategies supporting LL implementation

Since co-developed solutions and innovations do not develop their impacts overnight, long-term collaboration beyond the usual cycle of research projects is particularly important. Only with long-term commitment trust and cooperation can be expected from all stakeholders involved. This is particularly important because dealing with failures and unsuccessful innovations is an essential part of successful living labs in the long term. Experiences from development cooperations show that short term involvement in local context can be more harmful than no engagement at all. Commitment beyond the mere co-creation and innovation phase is therefore important and needs to be planned for from the start of living lab implementation or larger regional development planning. The development of business plans is an important means. However, since many of the solutions co-developed in soil health living labs are predominantly supporting public goods (e.g. improved soil related ecosystem services), business plans cannot simply be thought of in terms of market development. They must consider other financing channels which are particularly suitable for public goods, such as carbon farming schemes.
Creating new business models where soil health is considered always involves failures along the line. Experimenting new cropping systems may result in loss or reduced production. To make these business models attractive to farmers and landowners a solid plan is needed in which risks are shared in the agricultural production/food chain. In agricultural systems, this means an absolute loss of yield in the worst case. Increase profitability by securing markets of return on investments or creating new markets such as nature-based solutions and carbon farming, in collaboration with policy actors.

The topics in this Research and Innovation agenda should be used for promoting different types of regional activities. First of all the research and innovation that is still needed to develop new knowledge can be funded through national blue sky funding or Horizon Europe funding. Secondly, applied research can be funded by the same donors, but also by philanthropy and industry. This can be done through traditional project funding or by innovation calls where start –ups can apply for lifting the TRL level of specific practices in collaboration with the farmer and farmer advisor sector. These innovations should be focussing on tackling specific problems in specific pedo-climatic zones. A third way would be to explore pre-competitive investment options to avoid loss of time on complicated and time-consuming calls. Another opportunity lies in creating financial investment matching schemes such as public-private partnerships and beyond.

9.2 Policy for soil needs alleviation

Improve policy coherence between R&I policies (soil mission), environmental policies (soil monitoring law and biodiversity strategy), and agricultural (CAP) and climate policies. Among these policy fields, CAP has by far the largest budget and is therefore the largest lever for soil health improvement. Bug steps are being made at this moment (spring 2025), but we are authors of this document urge policy makers to keep continuing strengthening the legislation in development and ensure strong metrics to implement these policies.
To be able to make use of the scientific community we urge policy makers to be involved early on in the R&I process of the soil mission, the better can R&I outcomes be used for refining sector policies.

Science policy interface measures should therefore be embedded in soil health living labs. PREPSOIL deliverable 1.6 provides details on how science policy interfaces can be established in living labs. It stresses the importance of extracting learnings from the LLs which may inform science based advice to policymakers/civil servants, because some of the required soil management practices depend on changed framework conditions also from the policy side. The LLs – if successful in engaging regional policy makers/civil servants may thus serve as co-creation spaces also for developing appropriate policy support from the systemic perspective. And, since this ideally involves multiple stakeholder types, the classical Science-Policy interface should be broadened to a so-called Science-Policy-Society interface.

For policy it is important to incentivize investments in soil health by financial investment matching (building beyond the Public Private Partnerships principle) where the goals of the different policies are combined. This will enhance creative collaborations with a large diversity of actors in living lab and partnership settings. Such a pool of actors will be able to push for a feasible and acceptable sustainable transition pathway. Already in 2012 Otte et al., urged for policy-effective research. Although, we feel that since then, researchers are much better aware of their societal task, still it is important to keep the urgent needs within society, along with market drivers and trends in mind when new research is set up. Dealing with societal issues implies an integrated and system-oriented approach which combines soil, water, atmosphere, ecology, economy and socio-cultural elements. Effective policy research should include a strong dialogue between researchers and policy makers, for which both stakeholder groups should make an effort. Specific science brokers are needed to facilitate this, to make it into a true collaboration.

9.3 The role of LLs in addressing soil needs and challenges at landscape level.

In the definition of Mission Soil LLs, they are "place-based" R&I ecosystems involving land managers, researchers and other stakeholders in systemic co-creation for improved soil health. LLs are supposed to cover a certain area, landscape or region with comparable conditions and soil health challenges and include several sites (e.g. farms or other units of soil management), where co-creation experiments take place in a coordinated way (Soil Mission Implementation plan, 2022) while this may address systemic challenges at farm level (or business units in other land use types) the concept is not clear about how to improve soil health in an integrated landscape approach. In the field of biodiversity and (agricultural) landscape management Jackson et al. (2010) present a concept for ordering agri-biodiversity interventions at different scales, including field, farm, landscape and watershed levels. As illustrated in Fig 5 they suggested inserting the scale hierarchy in a two-dimensional matrix with time and institutional levels, suggesting that landscape and watershed levels would – tentatively and conceptually – match with rural-urban networks respectively a value chain approach. This is inspiring in respect to addressing soil needs because several of our regional assessments (D2.1 Bayer et al, 2023; Bayer et al., submitted) demonstrate that soil health improvements would require a systems approach reaching beyond the field and farm level and should be supported by the development of (new/alternative) value chains, which would remunerate land managers for changing practices and allowing for diversification of land use. Moreover, the idea of collaboration between stakeholders at a (sub-)regional area is supported by soil needs, which requires a landscape approach to capture the different soil health challenges across soil types and other spatial variation (topology, landscape type, natural vegetation etc.). Such as was demonstrated in the Valencian case study, where water management has changed the location of specific crops (irrigated agriculture is now possible on the hillslopes) causing a negative impact on soil erosion (Keesstra et al., 2017; Bayer et al., 2025). This calls for a more distinct approach to co-developing improved soil management at integrated, multifunctional landscape/watershed level than currently presented in the basic idea of soil health LLs. An advantage of this would be that it may allow to better address soil health challenges on soils with specific needs or conditions (erosion prone, high risk nutrient emissions, soil carbon protection) by joint land use planning, including reparcelling/land consolidation and/or financial compensation for reducing intensity in land use or set-aside.

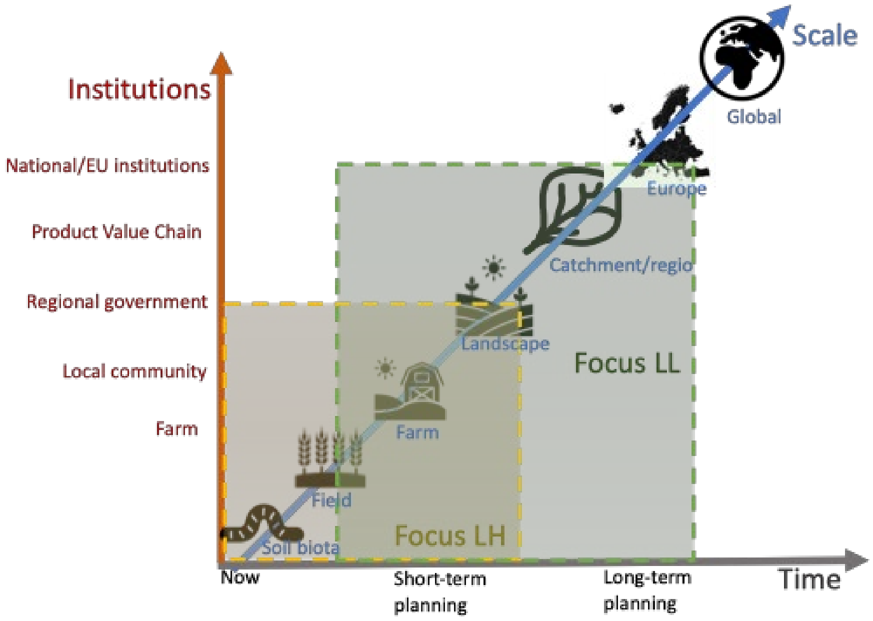


Figure 5: Operating space of Lighthouses (LH) and Living Labs (LL) in temporal and spatial space. In addition, institutional dimension is added (inspired by Jackson et al., 2022).

One example is the need for a landscape approach to identifying peat soils for conservation of soil carbon by rewetting (Mission soil objective #2) and for compensating land managers who depends on the land for e.g. livestock feed, grazing or proper manure distribution. This approach is currently practiced by the Danish authorities seeking to meet the national CO2 emission reduction targets by supporting the rewetting of peat soils by either entering into agreements re. financial compensation of landowners and/or land consolidation (by government purchase of available land and reparcelling in exchange for giving up peat soils or similar vulnerable soils. Based on a parliamentary decision re. measures to mitigate agricultures climate emissions in synergy with reducing Nitrate leaching and implementing nature restauration requirements, the government has created a new Ministry of Green Transition (Ministeriet for Grøn Trepart; 2024 (no English version). The Ministry and its "Agency for Green Transition and Aquatic Environment" has initiated via official law and regulations a network of catchment scale regional "tripartite governance units", which are multi-actor organisations - led by municipalities - responsible for establishing land use plans. The plans should determine which parts of the specific landscape within the catchments should be taken out of annual crop production to become barriers for nitrate leaching to the aquatic environment by combinations of set-aside, afforestation, rewetting and – possible – other forms of perennial land use (MGT, 2024). The actual implementation of the plans and their consequences for agricultural land use and production is still to be seen in the years to come. However, preparations to establish support schemes for co-creation of these processes are debated in parallel to the concept of LLs. In conclusion, the Region focused STRIA on soil health should include a landscape perspective calling for actions and knowledge production going beyond the field and farm levels.

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