Soil Mission Support

KNOWLEDGE NEEDS AND GAPS ON SOIL AND LAND MANAGEMENT

Grant Agreement 101000258
Deliverable 2.4
Version: 2.1
February 17th 2023

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DOCUMENT INFORMATION

Grant agreement	101000258
Project title	Soil Mission Support
Project acronym	SMS
Project duration	01 / 11 / 2020 – 31 / 10 / 2022
Related work package	WP 2 - R&I stock-taking and knowledge gap identification WP 3 - R&I roadmap co-creation
Related task(s)	Task 2.3 Content management of soil and land R&I knowledge, including mapping assessment and gap identification Task 3.2 Engaging with soil and land management actors
Lead organisations	INRAE, ZALF
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Submission date	30.06.2022
Dissemination level	public

DOCUMENT HISTORY

Date	Submitted by	Reviewed by	Version (Notes)
05 / 02 / 2022	Michael Löbmann	SMS Management Board	0.1 outline
25 / 05 / 2022	Katharina Helming	Peter Kuikman, Rocío Lansac, Elena Rodríguez Valín	0.2 full draft to reviewers
30 / 06 / 2022	Katharina Helming		1.0 final version to submit
30 / 01 / 2023	Michael Löbmann		2.0 revised version
17 / 02 / 2023	Michael Löbmann		2.1 revised version

Funded by the Horizon 2020 Framework Programme of the European Union

This project has received funding from the European Union's Horizon2020 Research and Innovation Programme under Grant Agreement No. 101000258. The content of publication is the sole responsibility of the authors. The European Commission or its services cannot be held responsible for any use that may be made of the information it contains.

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ABBREVIATIONS

C	Carbon
CAP	Common Agricultural Policy
CSA	Coordination and Support Actions
D	Deliverable
DG AGRI	Directorate-General for Agriculture and Rural Development
EC	European Commission
EU	European Union
HE	Horizon Europe
ICT	Information Communication Technology tools
JPI	Joint Programming Initiative
JRC	Joint Research Centre
LH	Light House
LL	Living Lab
MB	Mission Board
MO	Mission Objective
MS	Member State
R&I	Research and Innovation
SDG	Sustainable Development Goal
SMS	Soil Mission Support
SOC	Soil Organic Carbon
STI	Science Technology and Innovation
WP	Work package

ABSTRACT

Soil health is vital for many ecosystem services. The Horizon Europe (HE) Mission "A Soil Deal for Europe" aims to accelerate the transition to sustainable soil and land management and healthy soils through an ambitious transdisciplinary research and innovation (R&I) programme, largely based on actor engagement, Living Labs and Lighthouses. The H2020 Soil Mission Support (SMS) project supported the implementation of the HE Mission, and aimed to improve the coordination of R&I on sustainable soil and land management. Through a co-creation process together with actors, SMS collated available knowledge, actors R&I needs and identified R&I gaps that need to be addressed for successful transition towards sustainable soil and land management.

The first step was to identify existing R&I knowledge through a keyword-based analysis of scientific literature published and peer reviewed, related to sustainable soil and land management. The literature analysis addressed the full range of societal challenges, soil health objectives, land use types and knowledge domains necessary to capture the socio-ecological complexity of soil health. Covering some 15,700 scientific articles, this literature analysis represents the current peer reviewed knowledge stock on sustainable soil and land management. A textual analysis using the digital platform CorTexT was undertaken to explore the identified literature and submitted to project consortium internal experts, who analysed and processed the collected information of their respective area of expertise (Annex III). The literature analysis revealed that the societal challenges "reduce soil degradation" and "improve disaster control" have been studied extensively. Conversely, the societal challenges "mitigate land take" and "increase biodiversity" and the knowledge domains "science-based policy support" and "awareness, training & education" are less discussed. Factsheets presenting the results of the literature analysis per societal challenge were developed and can be found in Annex VIII. Note that as the key-word based literature search was limited to Scopus-indexed scientific journals, other publishing formats such as conference papers, books, book chapters, non-digitalized articles, grey literature, reports, patents, etc., may be underrepresented or not included in the used data base. The exclusive use of Scopus-indexed scientific articles provided quality insurance of the material through the publication peer-review system. Nonetheless, important documents and knowledge have been incorporated by the consortium experts when analysing the collected literature.

The second step was to consult actors through online workshops and surveys in order to gain a practice-oriented 'real-life' picture of current knowledge and R&I needs for swift implementation of sustainable soil and land management. This step was seen as complementary of the published and peer-reviewed literature.

Finally, after exploring our stocktaking of R&I from existing knowledge evidenced by literature review and the actor's knowledge needs identified from actor consultations, we identified R&I gaps. The main knowledge gaps across all Mission Objectives were of socio-economic nature: drivers and causes of land degradation, knowledge management, governance and policies for inciting improved management, and interaction with other sectors are not sufficiently understood. Second, the HE Missions' focus on improving soil literacy was supported by the literature analysis and by the actor consultation, which both revealed knowledge gaps related to education and capacity building in all land use types and domains affecting soil health: production, consumption, trade, policy and governance. Thirdly, there is a gap in the long-term implementation of a new mode of knowledge co-design, where researchers and practitioners together develop solutions for sustainable soil and land management in a real-world context. The HE Missions' focus on Living Labs and Lighthouses has the potential to close this gap. Finally, there is a need to define several concepts (e.g. soil health, soil degradation, footprint). Such definitions should be shared and will be a basis to identify relevant indicators and respective thresholds, and to develop guidelines to support monitoring programmes in order to translate knowledge into evidence for decision making.

The outcome of the deliverable is a list of validated R&I gaps across all Mission Objectives which will feed into the SMS roadmap and the HE Mission.

1. INTRODUCTION

Soil health is vital for the delivery of food, energy, and biomaterials, as well as climate change adaptation and mitigation, biodiversity below and above ground and a wide range of further ecosystem services. Pressure on land and soil is growing due to competing demands for land and bio-based products. A sustainable soil management that satisfies the increasing demand and avoids soil degradation requires coordinated research and innovation (R&I), evidence-based and integrated policies and involvement of a large diversity of actors, from producers to citizens. The Horizon Europe (**HE**) **Mission "A Soil Deal for Europe**" will actively address the above in the coming years.

1.1 A Soil Deal for Europe

HE Missions are a new pathway to bring forward concrete solutions to some of our greatest challenges. The main goal of the HE Mission "A Soil Deal for Europe" is to establish **100 Living Labs and Lighthouses to lead the transition towards healthy soils by 2030**. According to an assessment undertaken by the Joint Research Centre (JRC) and the Mission Board, 60-70% of soils in Europe are in an unhealthy condition. The HE Mission aims at a transition towards healthy soils through:

- Funding an ambitious R&I programme including a strong social science component;
- Putting in place an effective network of 100 Living Labs and Lighthouses to co-create knowledge, test solutions and demonstrate their value in real-life conditions;
- Developing a harmonised framework for soil monitoring in Europe;
- Raising people's awareness on the vital importance of soils.

1.2 The Soil Mission Support project

The **H2020 Soil Mission Support (SMS) project** supports the European Commission (EC) and the Mission Board (MB) of the Horizon Europe (HE) Mission in delivering the objectives and related targets of the "Soil deal for Europe" (EC, 2021). SMS employs an approach to create an effective framework for action in the wider area of soil health and land management by coordinating efforts and pooling resources, by developing a coherent portfolio of R&I activities. The action fields range from agriculture and forestry to spatial planning, land remediation, climate action, and disaster control. Activities include:

- The analysis of the existing R&I knowledge on soil and land management;
- The analysis of actor identified needs for R&I on soil and land management;
- The identification of gaps and types of action for intervention including Living Labs and Lighthouses.

SMS outcomes and results include:

- An actor-based, co-created roadmap for R&I to support the HE Mission "A soil deal for Europe";
- Improved coordination with existing activities in Europe and globally, thereby raising visibility and effectiveness of R&I funding;
- Identification of and learning from existing and potential Living Labs and Lighthouses for co-creating, prototyping, testing and demonstrating solutions in order to understand and explore opportunities and find solutions for competing demands of soil use.

1.3 Objectives of this deliverable

This deliverable is part of SMS Work Package 2 (WP). It has two main objectives:

- **R&I stocktaking**: The objective here is to identify and assess existing research and knowledge relevant for soil and land management through a keyword-based analysis of published scientific literature. Focus will be laid on operational knowledge that supports improved soil and land management. This includes innovative practices and policies as well as indicators and tools for assessment and monitoring. It can be derived directly from basic science as well as from applied research. The mapping of the R&I actors' landscape (recent H2020 projects, European R&I institutions and Living Labs) from deliverable D2.3 (Kassai et al., 2022) will feed into the R&I stocktake.

- **Gap identification**: The objective is to identify R&I gaps by comparing the knowledge stock with the actors R&I needs prioritised in deliverable D3.4 (Maring et al, 2021). If a need is formulated, but knowledge is available, knowledge sharing needs to be improved. If available knowledge is insufficient, the R&I gap needs to be addressed.

Through exploring our knowledge stocktake of related R&I via a literature review and the actors' knowledge needs, as identified from actor consultations, we derive and identify R&I gaps. This report delivers valuable perspectives to support the co-creation process of the SMS Roadmap for R&I on soil and land management in SMS WP3. This Roadmap will build up on the here presented deliverable and will entail an overarching prioritisation of the R&I needs.

1.4 Structure of this deliverable

The R&I stocktake and actor identified needs are reported in this deliverable and compared for gap identification. Chapter 1 is the introduction. In chapter 2, the methodology as based on the SMS knowledge matrix and on the HE Mission Objectives is described. Chapter 2 also focuses on the methods used for the R&I stocktaking and the gap identification. Chapter 3 provides a concise overview of the available knowledge stock on soil and land related R&I, the actors needs and the identified R&I gaps. In chapter 4, the main results of the deliverable are discussed and synthetized. Several recommendations are given at the end. Multiple annexes provide more details on the methodology, the main results related to the literature analysis, as well as factsheets on the existing knowledge per societal challenge.

2. METHODOLOGY

2.1 Analytical framework

2.1.1 The SMS Knowledge Matrix

A systemic integrated scientific approach to soil science, that includes all land use and management types, and that goes beyond knowledge production, into a more strategic, solution and practice-oriented mode is required. Towards this end, we developed a knowledge matrix that covers all land use types and links to key soil related societal challenges and the Sustainable Development Goals (SDG) (Löbmann et al., 2022). The analytical framework (knowledge matrix) of the SMS project is compatible with the implementation plan of the HE Mission 'A Soil Deal for Europe' (EC, 2021). The ambition was to promote holistic, trans-disciplinary and participatory research on sustainable soil and land management including measures towards its practical implementation.

The SMS knowledge matrix (Figure 1) links eight key soil related societal challenges (columns) to nine key knowledge domains (rows) needed in order to ensure practical transition towards sustainable soil and land management. 'Living Labs & Lighthouses' are emphasized (in grey), since they display a key strategic element for the implementation of the Horizon Europe Mission.

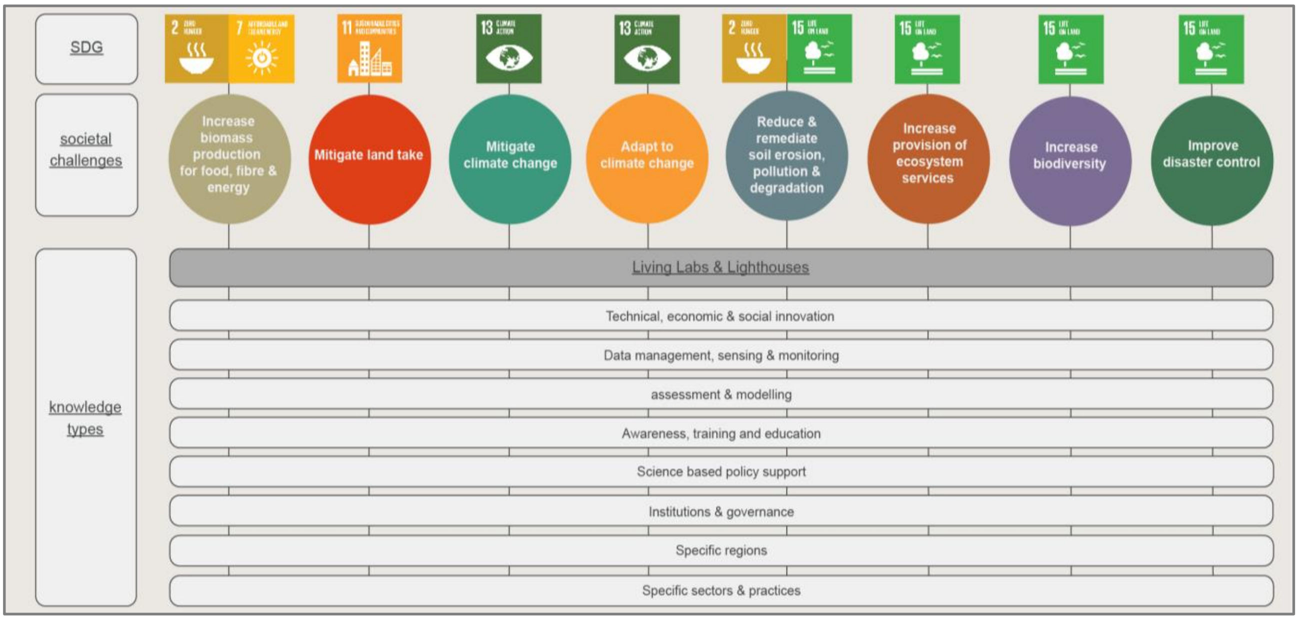

Figure 1: The analytical framework (knowledge matrix) of the SMS project (source: Löbmann et al., 2022).

2.1.2 The HE Mission Objectives

As for the needs and gaps assessment, we followed the Mission Objectives (MO) as a guiding structure (EC, 2021). The eight Mission's Objectives, as shown in Annex I, are closely related to those of the European Green Deal, the SDGs and other EU policies and strategies. In addition, the HE Mission defines four transversal, operational objectives that reflect the mechanisms to address the eight interconnected specific objectives:

- 1: Build capacities and the knowledge base for soil stewardship
- 2: Co-create and upscale place-based innovations to improve soil health in all places
- 3: Develop an integrated EU soil monitoring system and track progress towards soil health
- 4: Engage with the soil user community and society at large.

2.1.3 Relationship between the SMS Knowledge Matrix and Mission Objectives

Figure 2 shows the connection between the SMS knowledge matrix (central column, where the coloured blocks are the societal challenges and the white blocks are the knowledge domains), the eight Mission Objectives (at the left side) and Mission "Building Blocks" or Operational objectives (at the right side).

Each of the Mission Objectives can be linked to the SMS societal challenges, which were based on the sustainable development goals. The SMS societal challenges, as well as the Mission Objectives, are formulated in an active way to emphasize the action towards the healthy soils goal. The lines in the figure mean that there is a relationship between the different elements. The links are mainly between the Mission Objectives 1-6, which are based on avoiding or battling soil threats. When looking at the SMS knowledge domains (central column, white blocks), they are linked both with the Mission Objectives 7 (reduce the EU global footprint on soils) and 8 (Increase soil literacy in society across Member States) of the Soil Mission, and the Mission building blocks.

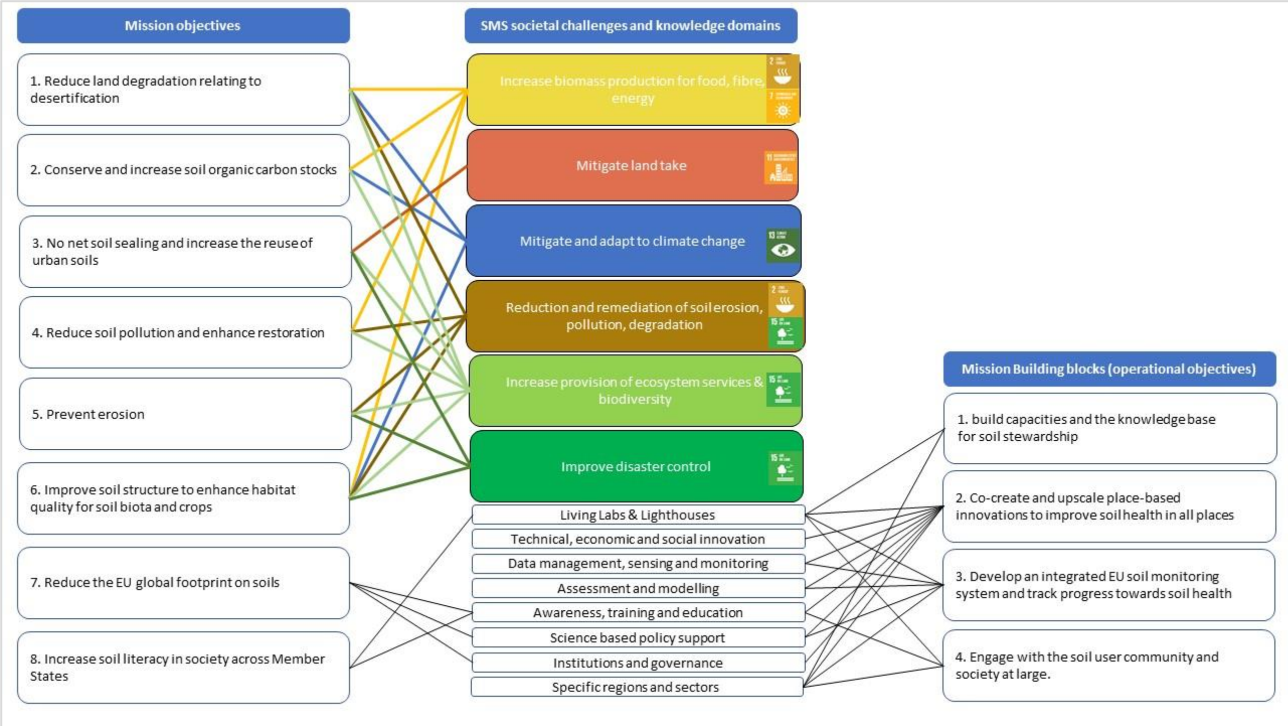

Figure 2: Connections between the Soil Mission Objectives, the SMS knowledge matrix and the Soil Mission Building Blocks.

2.2 Scientific literature stock assessment

2.2.1 Literature review

A quantitative and qualitative analysis of scientific literature is performed in order to provide a comprehensive and detailed overview of existing R&I knowledge within the broader theme of sustainable soil and land management. The structural basis for the literature analysis is the SMS Knowledge Matrix (Figure 1) as based on the Mission Objectives. The knowledge matrix was constructed from the perspective of societal challenges and their links to the SDGs, which we found to be a tangible approach for the literature review.

The approach used for the literature review consisted of two steps:

- i) Identification of scientific journal articles relative to the SMS Knowledge matrix through a bibliographic search process, inventorying existing articles,
- ii) Textual analysis of the articles and identification of thematic subgroups.

- **Articles identification**

The objective was to inventory existing scientific articles related to i) the respective societal challenges (columns), combined with ii) the respective knowledge domains (rows). Details on the inventory and search are provided in Annex II. For each cell of the extended knowledge matrix ('societal challenge' X 'knowledge domain'), the related articles available were identified through a bibliographic search in Scopus (Elsevier). Only peer-review journals were included in the inventory, as we exclusively focussed on international, peer reviewed research articles to stay within the boundaries of internationally accepted scientific quality management. The article identification was carried out during 2021 and was limited to articles published until 2020.

A scoping exercise was conducted on the Scopus database to build-up the search strings. The detailed search request is presented in Annex II. Among all articles identified, a screening process was conducted in order to select only relevant articles. Articles that successfully passed the screening process were included in a database, named the SMS corpus.

The here performed key-word based literature search was limited to Scopus-indexed scientific journals. Although our search strategy is robust for peer-reviewed scientific journal articles, other publishing formats such as conference papers, books, book chapters, non-digitalized articles, grey literature, reports, patents, etc., may be underrepresented or not included in the used data base. In summary, non-scientific studies, or non-peer-reviewed scientific articles are not present in the inventory of this literature review. This is in contrast to initial plans, which also included the analysis of grey literature. The initial plan was abandoned because of three reasons. First, the exclusive use of Scopus-based articles guaranteed quality assurance through the publication peer-review system. Second, the developed knowledge matrix including the various knowledge domains made the analysis much more comprehensive than initially foreseen and resulted in a much higher number of scientific articles to be analyzed than foreseen. Third, grey literature is mainly produced by non-scientific actors, and their knowledge needs were captured through the actor inclusive needs analysis. Nonetheless, important reports and information have been incorporated by project consortium internal experts, who analysed and processed the collected information of their respective area of expertise.

Further, the Scopus database is biased towards journals that publish in English language (Sweileh et al. 2017), as well as this study was generally limited to articles published in English, in order to avoid a bias of used literature towards publishing languages that are represented within the project consortium. Thus, output from non-English journals and articles is not reflected in the literature review, which may be of particular importance for publications in early years, when English was not yet broadly established as a global standard for scientific publishing. Nonetheless, we consider the used data basis for this review article as representative for the overall trends within the scientific field, since it includes major scientific journals that reflect up-to-date developments through their published articles. We want to point out in particular, that absolute numbers of identified articles should be regarded carefully and rather seen as trends when comparing different focus topics with each other. They do not reflect absolute numbers of published articles.

- **Content analyses**

The resulting SMS corpus was analysed to obtain a global understanding of its content. Textual analysis allows for an automated examination of a corpus and provides a means of quickly exploring of the literature to get an idea of the themes covered and the relationships between these themes (Reboud et al., 2012; Sandoval and Tarot, 2014; Tancoigne et al., 2014; Réchaudère et al., 2018). We applied this approach to the SMS corpus identified through the bibliographic search. Per article, the items used for the analysis of the corpus were the title, abstract, keywords, authors, publishing countries and institutions. The textual analysis consists of two main steps (EL Akkari et al., 2018) described in Annex III. We used the text analysis program CorTexT Manager. A presentation of the program is also available in Annex III. Per cell of the SMS Knowledge Matrix, a content analysis of the corpus was conducted.

2.2.2 Overview of the European R&I actors' landscape

The publishing actors identified in the literature analysis do not cover all relevant actors active in R&I and implementing knowledge. The information on the R&I landscape in the EU is needed in order to support the formation and implementation of the HE Mission 'A Soil Deal for Europe'. To address this gap, the SMS project provided an overview of the current European R&I landscapes on sustainable soil and land management, including H2020 R&I projects (ongoing, or recently finished), institutions, and networks, as well as Living Labs in another deliverable D2.3 'Factsheet based overview of soil and land related recent H2020 projects, European R&I institutions and Living Labs' (Kassai et al., 2022). Here, the R&I landscape was assessed in the context of the eight objectives of the Horizon Europe Mission 'A Soil Deal for Europe' and aims to supply a structural overview of R&I hotspots within the research landscape. Annex IV presents the different methods which were used to identify each R&I actor.

2.3 Actor needs assessment

The purpose of the actor needs assessment is a collection of practice related "needs" and "interests" of actors that are, or will be, engaged in sustainable soil and land management. These needs are not limited to R&I, but can comprise other needs such as better collaboration, different governance structures, specific programs or funding. The actor needs were collected in SMS Deliverable 3.4 "Report on prioritization of actor needs" (Maring et al., 2021), and relate to SMS Deliverable 3.3 "Actor engagement guide" (Brils et al., 2021), and SMS Deliverable 3.2 "Detailed actor analysis" (László et al., 2022).

For all engagement activities (workshops and surveys), it was ensured that a broad and representative pool of actors was invited. Primary source of information for achieving insights in the actor needs was an SMS online survey on actor needs (Maring et al., 2021). Furthermore, two workshops were held with actors for gaining more details (Maring et al., 2021). The survey focused on actor needs and priorities related to achievement of the objectives of the Soil Mission. The survey was sent out to the list of actors as identified in D3.2 detailed actor analysis (László et al., 2022). This is a very representative group, covering all land uses and different actor categories and, because of the networks that are represented in this group, also the different member states. For each of the eight Soil Mission Objectives (Annex I), the survey respondents were asked to indicate how important (of great significance or value) and how urgent they consider the specific objective for their organisation. In the survey as well as in the workshops, the actors were asked to specify their needs regarding the Mission Objectives. A more detailed description of the methods is given in Annex V.

2.4 R&I gap assessment

Figure 3 describes the working steps followed for the R&I gap assessment. The actors' R&I needs were compared with the knowledge stock per Mission Objective to identify R&I gaps. The knowledge stock was reviewed per societal challenge and knowledge domain. For the gap assessment, the identified existing literature was sorted per Mission Objective. The needs formulated by actors were used as templates for the gap assessment, since they represent actual and timely requests from a practical point of view. For specification, these needs were compared with the knowledge stock. If a need was formulated, but knowledge was available, knowledge sharing needs to be improved. If available knowledge was insufficient, then a gap was identified and listed. Already identified R&I gaps were added from an early confidential deliverable (D2.1) 'Reflection analysis on very urgent R&I gaps' (Löbmann et al., 2021). This report assessed urgent R&I gaps as formulated by (then) ongoing or recently finished H2020 projects related to soil and land management (e.g. EJP SOIL, CIRCASA, INSPIRATION, etc.), in order to support the formation of the Soil Mission at an early stage.

We validated the obtained R&I gaps in separate workshops with (a representative group of) actors, each addressing a specific land use (i.e. agricultural, forestry, natural, industrial and urban) and due to its novel character, a separate workshop was held on Mission Objective 7 "Reduce the EU global footprint on soils". Around 100 participants from 20 different EU countries took part in the workshops. Participants were HE mission board members, experts and initiatives that were identified in D2.3 (Kassai et al., 2022), key actors as identified in D3.2 (László et al., 2022) and SMS advisory board members. Participants were asked to (i) validate the obtained gaps and (ii) identify missing gaps. Validation criteria included completeness in terms of research field and knowledge domains, coverage of specific regions and socio-economic conditions, depth and accuracy, relevance for innovation in technology and practice, impacts, knowledge gaps and required R&I for filling these gaps. The outcome of the workshop is a list of validated R&I gaps across all Mission Objectives which will feed into the reporting, the SMS roadmap and finally support the Soil Mission.

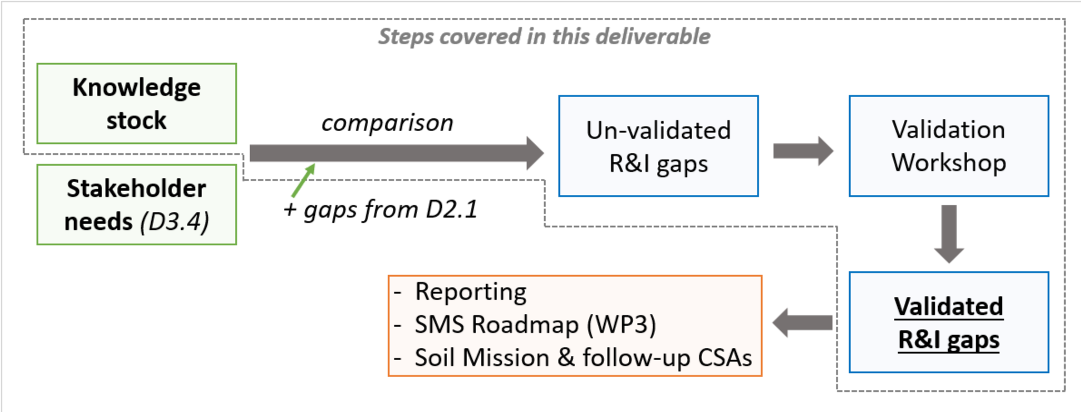

Figure 3: Diagram of the procedure followed to identify the R&I gaps.

3. RESULTS: SOIL MISSION RELATED R&I GAPS

3.1 Stocktake of scientific knowledge on sustainable soil and land management

3.1.1 Literature review results

- **Interest over time**

The literature review yielded 15,679 relevant articles for the combined 8 societal challenges in relation to soil and / or land. This high volume of bibliography highlights the fact that the issue is already widely studied by scientists. First articles in Scopus were identified around 1919 and numbers of publications surged considerably since 2005, with more than one thousand articles a year (Figure 4). More than a third of all the articles (5,599/15,679) were published in the last five years of this assessment (i.e. 2016-2020). Except for the societal challenges "reduce soil degradation" and "improve disaster control", for the other 6 societal challenges, no articles were identified before 1974. These 6 societal challenges seem to be more recent concerns.

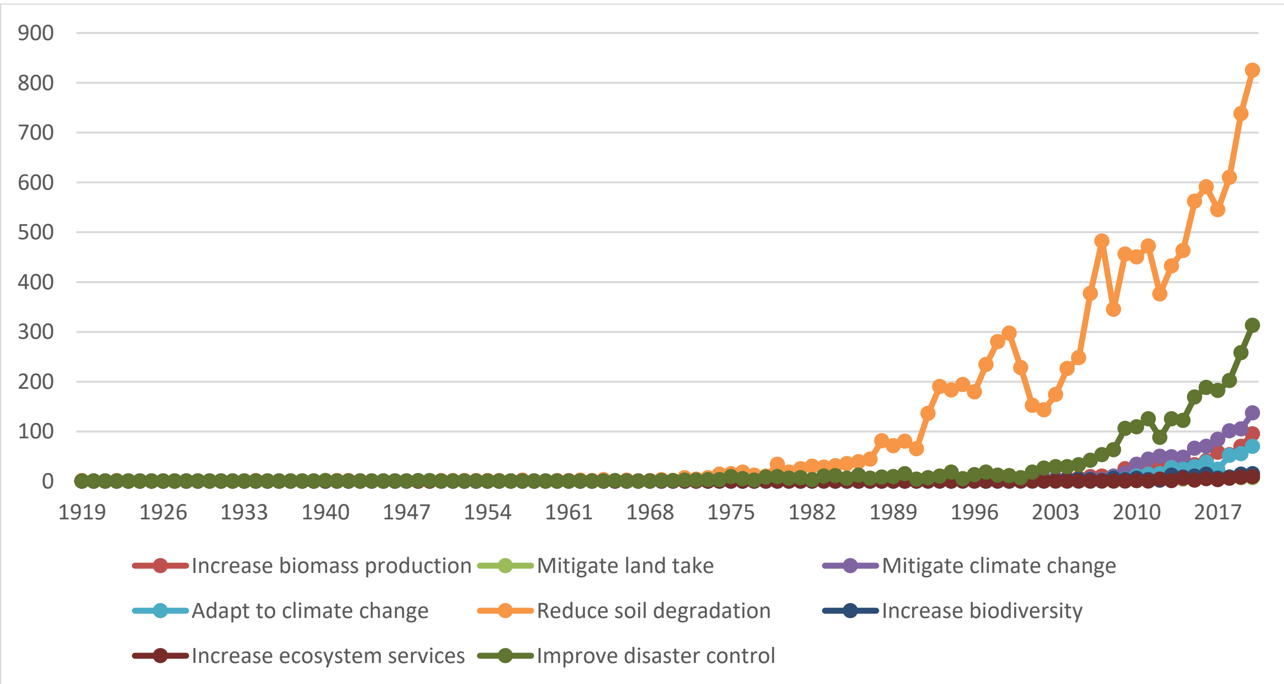

Figure 4: Chronologic number of articles since 1919 published per societal challenges

- **Existing research & knowledge**

The full corpus was analysed textually to review the themes addressed in the 15,679 articles. Overall, the main terms found in the articles are, in descending order: “pollution control”, “land use”, “soil erosion”, “climate change”, “contaminated soil”, “water quality”, “air pollution”, and “management practices”. Main terms relate to degradation processes and soil threats. The map of the articles’ textual content is presented in Figure 5. The main terms coalesce together in five clusters around the themes 1: “land use & carbon & air pollution”, 2: “water pollution”, 3: “soil erosion”, 4: “soil pollution” and 5: “water resources”. There was no overlap between these clusters and some minor connectivity was evident between cluster 5 with clusters 1, 2 and 3. Reduce soil degradation is the societal challenge with the most articles (11,285). Therefore, the main terms used in the full corpus (15,679 articles) come mainly from this societal challenge. The clusters are similar to the clusters found in the corpus of the societal challenge “reduce soil degradation”. Prominent terms like biodiversity, ecosystem services or food production were not present among the identified major terms, probably since these terms are related to societal challenges that yielded fewer articles in this assessment.

Table 1 presents the clusters of the main terms used in each corpus per societal challenge. Some clusters can be found in various societal challenges, such as the cluster “soil carbon” found in both the societal challenges “increase biomass production” and “adapt to climate change”.

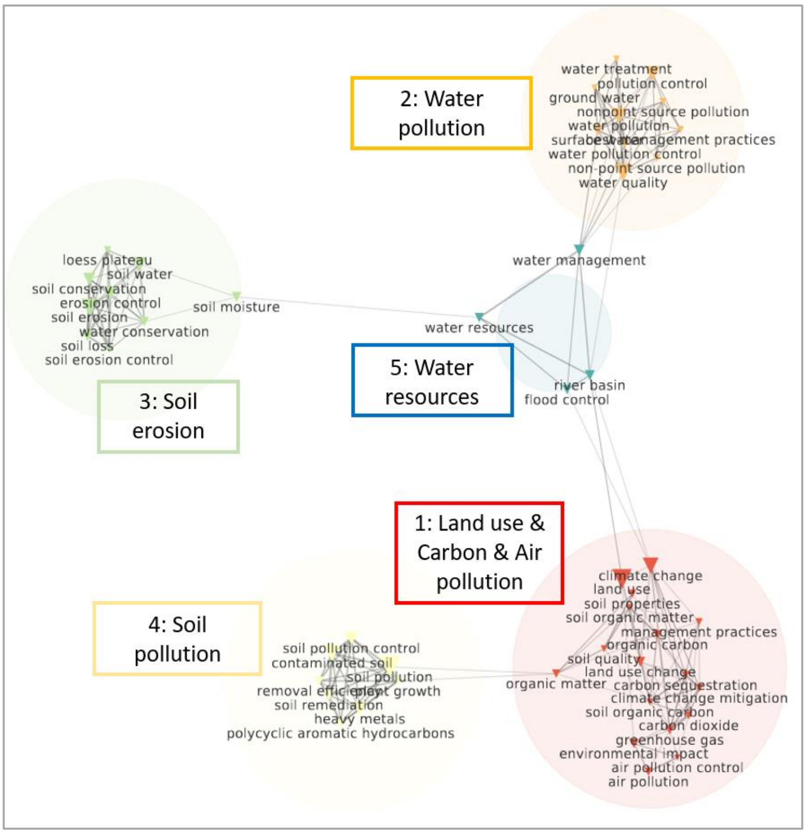

Figure 5: Overall cluster map of the main terms used in the full corpus (15,679 articles).

Societal challenges	Cluster denomination of the main terms per societal challenge
Increase biomass production	soil carbon / soil water / nutrient use efficiency / land use / soil bulk density
Mitigate land take	information system / risk assessment / life cycle / economic growth
Mitigate climate change	mitigation / soil carbon / emission reduction / N_2O & CO_2
Adapt to climate change	adaptation strategies / water stress / soil carbon & soil fertility / urban area & surface temperature / forest management / sea level
Reduce soil degradation	soil pollution / water pollution / soil erosion / air pollution / organic matter / risk assessment
Increase biodiversity	environmental impact assessment / soil biota / biodiversity conservation
Increase ecosystem services	biomass production / carbon sequestration / water regulation
Improve disaster control	risk management / water resources management / soil water / land management

Table 1: Overview of the cluster of the main terms used per societal challenge.

- **Topic of interest**

Not all 8 societal challenges have been studied the same way (Table 2 and Figure 6). Some societal challenges have been studied extensively such as “reduce soil degradation” and “improve disaster control”. Conversely, the societal challenges “mitigate land take” and “increase biodiversity” are less discussed. The same pattern is noticeable with regard to the knowledge domains (Table 2). Some knowledge domains have been studied extensively such as “assessment & modelling” and “basic knowledge production[1]”. Conversely, the knowledge domains “Living Labs & Lighthouses”, “awareness & education”, “science-based policy support”, “institutions & governance” are rather little discussed. Out of the 88 cells of the knowledge matrix (Table 2), 33 cells yielded less than 5 articles. It means for the 33 cells either the chosen search method was insufficient, or the existing R&I literature on the topic is very low to non-existent.

A more detailed overview on the results of the literature review is given in Annex VIII and Annex IX. In Annex VIII, factsheets presenting briefly the key findings of the literature analysis per societal challenge are to be found. The factsheets can be used to get an overview of the existing R&I knowledge. Whereas in Annex IX a detailed analysis per societal challenge and knowledge domains is given.

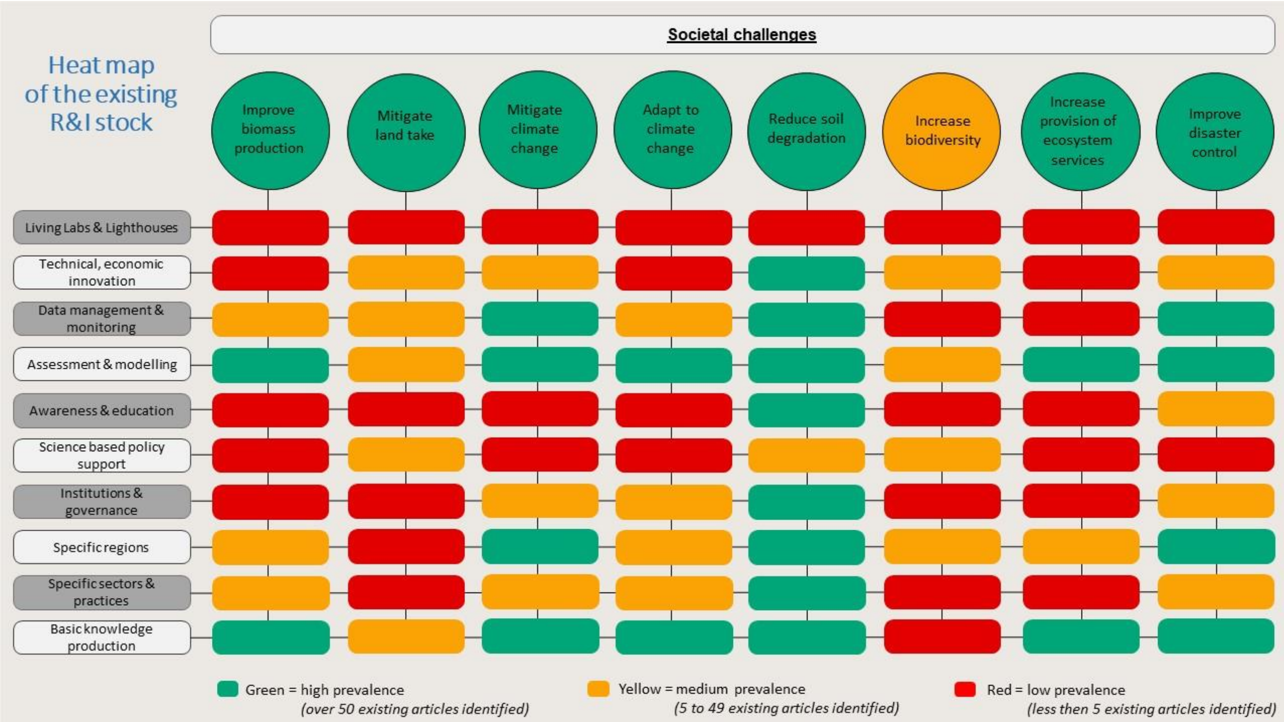

Table 2: “Heat map” indicating the prevalence of existing R&I knowledge in the scientific literature reviewed.

[1] *Basic knowledge can be seen as research dedicated to the study of a dedicated process, without any presumed application (e.g. studying the speciation of trace elements, identifying forms of carbon, understanding trophic chains).*

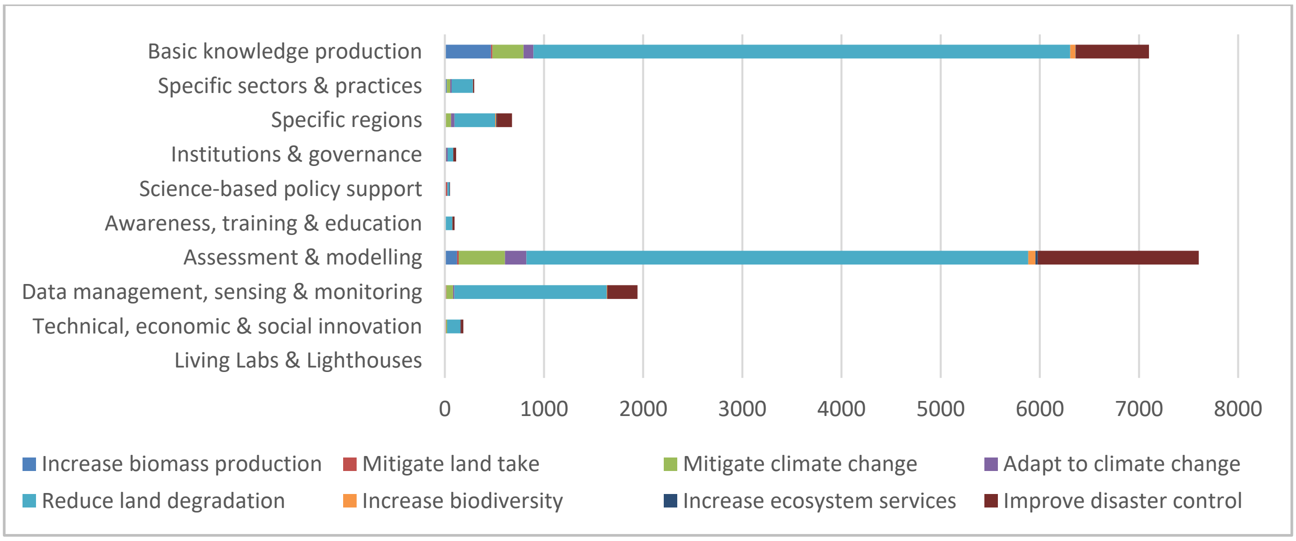

Figure 6: Number of articles per SMS knowledge domain and societal challenge.

- **Main specific regions covered and main sectors/techniques investigated**

Within our literature review, we identified if specific areas or regions were studied (Table 3), as well as if different techniques or solutions were promoted (Table 4). It appears that depending on societal challenges, different kinds of areas/regions were studied (Table 3). As an example, in the here identified articles, soil and land degradation were investigated in quite all environments except peatland which is only studied towards climate change mitigation. Mediterranean, coastal/island, mountain and cities/brownfields are the main regions/areas covered by the here identified research.

Regions/areas	Mediterra-nean	Boreal	Tropical	Island and coasts	Mountains	Cities and brownfields	Karsts	Peatland
Increase biomass production	X	X		X				
Mitigate land take						X		
Mitigate climate change	X	X						X
Adapt to climate change	X			X	X	X		
Reduce soil degradation	X	X	X	X	X	X	X	
Increase biodiversity	X							
Increase ecosys-tem services	X			X	X	X		
Improve disaster control				X	X			

Table 3: Overview of the main studied regions/areas per societal challenge.

Depending on the societal challenge, different sectors and techniques were studied (Table 4). Agroforestry is often investigated and presented as a valuable option to increase biomass, mitigate/adapt to climate change, improve ecosystem services, control disaster and reduce soil degradation. Few proposed and studied solutions imply a rethinking of agricultural systems by including livestock into crop landscapes, or developing agroforestry. Other studied options are pushing techniques that improve a specific practice (e.g. include soil amendments, develop intercropping, reduce tillage...) and that are easier to implement.

Sectors and techniques	Inter-cropping	Reduced or no-till, conservation agriculture	Mixed livestock and crop systems	Soil amendments *(compost, manure, biochar)*	Vineyards	Agroforestry	Orchards	Sealing-desealing, permeable pavement & contamination remediation
Increase biomass production	X	X		X		X		
Mitigate land take								X
Mitigate climate change		X		X		X		
Adapt to climate change	X	X	X	X		X		
Reduce soil degradation	X				X	X	X	
Increase biodiversity								
Increase ecosystem services						X		
Improve disaster control	X		X			X		

Table 4: Overview of the main studied sectors/techniques per societal challenge.

- **Main actors**

Identified studies were mainly published by institutions located in the European Union, China and North America (Figure 7). 30% of all articles were carried out in the European Union (4,633 articles). This number raises to 39% when including associated European countries such as the United Kingdom, Switzerland, and Norway (6,086 articles). A substantial proportion of the articles were also equally conducted in China and the United States (24%). In Europe, the United Kingdom followed by Germany and Spain are the countries who published the most articles (respectively 7%, 5% and 4%). Ten European institutions were involved in the production of at least 60 identified articles each (Figure 8). The main institutions involved in Europe are Wageningen University & Research (Netherlands), Consejo Superior de Investigaciones Científicas (Spain) and Centre National de la Recherche Scientifique (France), with 194, 151 and 104 identified articles respectively.

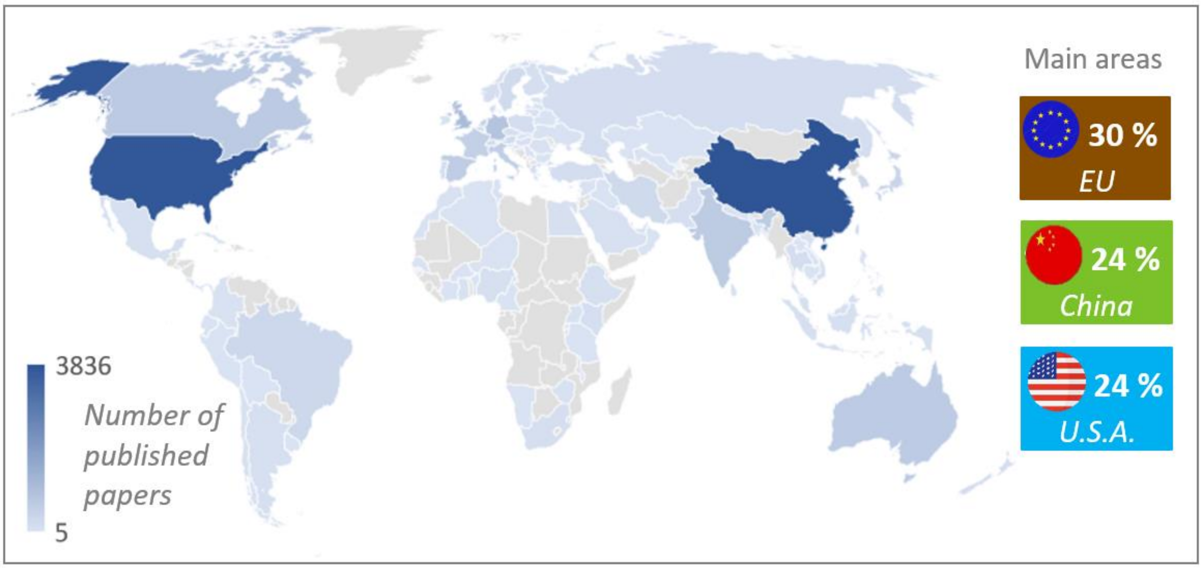

Figure 7: Concentration of publications per country for all 8 societal challenges.

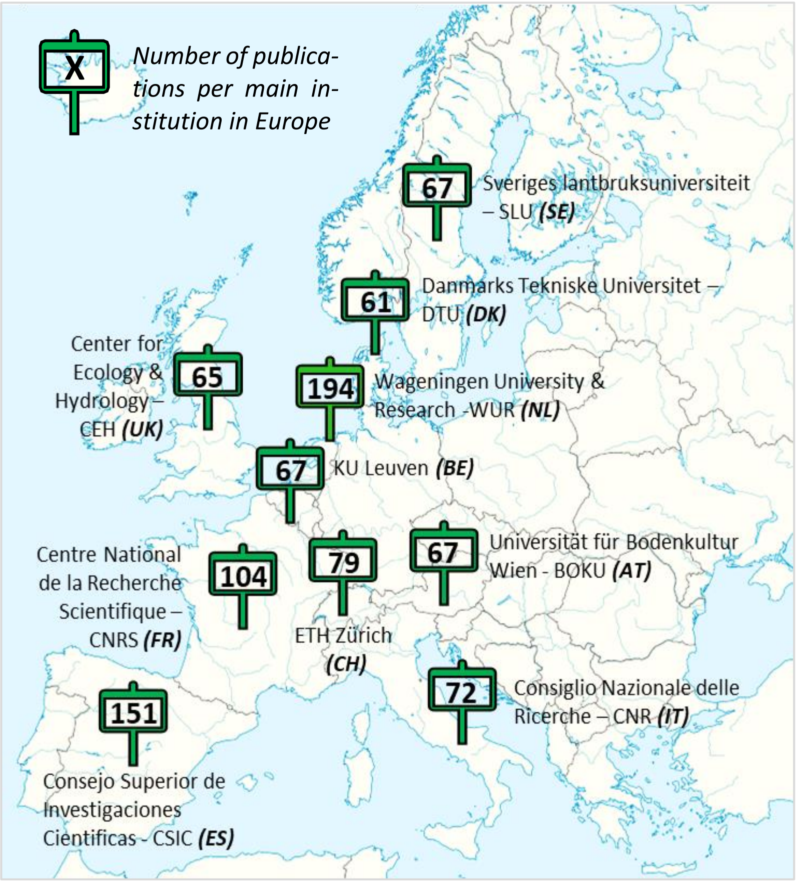

Figure 8: Map representing the main soil and land researching institutions in Europe.

3.1.2 Overview of the European R&I actor's landscape

SMS Deliverable 2.3 (Kassai et al., 2022) provides an overview of the current European R&I landscape on sustainable soil and land management. The report identified:

- **184 projects**, that is to say, 87 soil and land-related H2020 projects and 97 JPI URBAN, JPI FACCE, and JPI CLIMATE projects,
- **195 institutions and 30 networks**,
- **240 potential Living Labs**.

The assessment of the identified soil and land-related institutions, networks, and projects that support the eight objectives of the HE Mission gives an overview of the existing knowledge and potential gaps:

- Regarding institutions and networks, the MO8 (Increase soil literacy in society across the Member States) showed the least interest followed by MO7 (Reduce the EU global footprint on soils) and MO3 (No net soil sealing and increase the reuse of urban soils).
- In the case of projects, the least interest was shown for MO3 followed by MO5 (Prevent erosion) and MO8.
- For Living Labs, again MO3 seemed to be underrepresented within existing LLs for 21 MS.

Thus, the top three Mission Objectives, which need further study considering all the results from institutions, networks, projects, and Living Labs are MO3, MO7 and MO8.

3.2 Actors' needs regarding knowledge for soil and land management

The results of actors' needs (survey and workshops) are described in D3.4 (Maring et al., 2021). The description of the respondents is given in Annex VI and the list of prioritized needs in Annex VII. The general results are shown in Table 5 with a heat map of actors' needs per Mission Objectives and knowledge domains.

After a joint analysis and synthesis of the outcomes of the survey as well as the workshops, it is concluded that the generic actors' needs are: Funding, Legislation/policy frameworks, Knowledge/R&I for informed policies and measures, Awareness raising and communication. In most cases, the needs were not specified as specific R&I needs under the survey/workshops, but more generally that there is a need for more funding for R&I, awareness activities, better (legal, policy) support etc. Therefore, a lot of overlap could be seen between the different objectives.

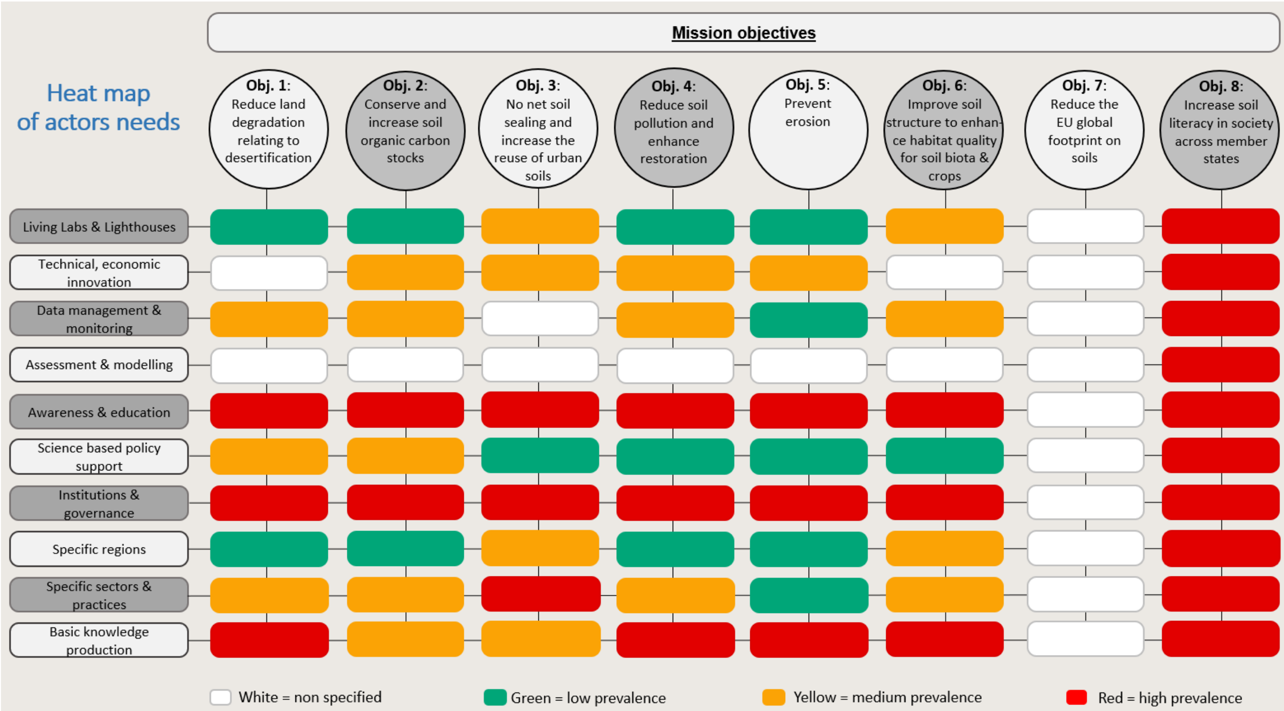

Table 5: Heat map of actors' needs.

3.3 R&I gaps regarding sustainable soil and land management

The actors R&I needs were compared with the knowledge stock per Mission Objective to identify R&I gaps. If a need was formulated, but knowledge was available, knowledge sharing needs to be improved. If available knowledge was insufficient, then a gap was identified and listed. To make use of available resources, more gaps were also added based on D2.1 'Reflection analysis on very urgent R&I gaps' (Löbmann et al., 2021).

The general results are presented in Table 6 in the form of a heat map of R&I gaps per Mission Objectives and per knowledge domains. After an analysis and synthesis of both the outcome of the desk studies as well as the workshops, it is concluded that the generic R&I gaps are: Funding, Legislation/policy frameworks, Knowledge/R&I for informed policies and measures, Awareness raising and education. The main detailed gaps are presented below per Mission Objective. Several identified R&I gaps related to multiple or all Mission Objectives are outlined here in order to emphasize the holistic character of R&I activities for sustainable soil and land use.

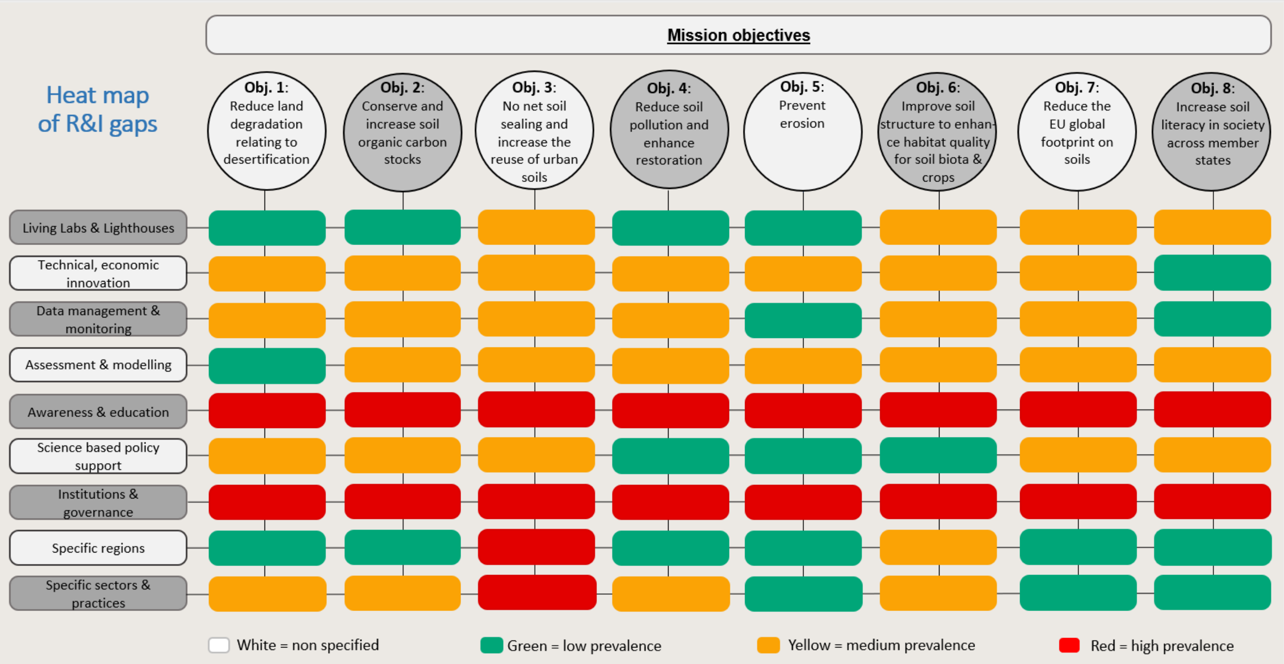

Table 6: Heat map of R&I gaps.

3.3.1 General gaps

Integrated Research on Multiple Scales

A very high need for more integrated, practice-oriented, location-specific and interdisciplinary R&I approaches combined with interactions across sectors, global collaboration including stakeholder participation, multi-stakeholder and multi-scale approaches need to be broadly established in all soil and land use sectors. Further, strategies to overcome conflicts of interest amongst stakeholders and frameworks for informed decision making need to be developed. To enable a broad knowledge exchange across regions, European networks of Living Labs and Lighthouses need to be connected. Hence, development of monitoring processes for evaluation of Living Labs and Lighthouses is recommended. Collaborative development and demonstration in communities of practice can be promoted by providing practical advice and scientific support for practitioners, and through developing success stories. For this, dedicated programmes to unlock the potential of integrated management is needed, that will aid to translate conceptual frameworks into practical advice. Improved exchange among practitioners can be achieved by creating farmer-field schools, demo farms and innovation hubs.

Promotion of systemic and holistic assessment and modelling strategies are recommended to improve understanding of long-term dynamics in soil quality, soil functions, food security and human health. Integrated research in soil ecosystem services supports the early identification of trade-offs and synergies within areas with multiple challenges and needs. Sustainability barriers such as biophysical requirements and limits in current soil management system are needed to be identified and provided with proper solutions. Practitioner based identification of research topics and approaches require the proper development of frameworks and tools for informed decision making. Precision farming applications for site-specific management are encouraged. For this, new initiatives such as application of 3D conceptual site models / digital twins to site management can be beneficial. Moreover, development and promotion of circular economy approaches and soil health protecting including urban land use, user friendly technologies is expressed. Raising awareness that cities are part of nature, especially to make cities part of the natural ecosystem, is emphasized. For this, development of operational tools is required to enable stakeholders to manage urban soils sustainably (e.g. Geospatial Decision Support Systems).

Innovation Based Solutions

There is a general need for innovation, technologies and eco-engineering that allow or encourage sustainable soil and land management and nature-based solutions. Available machines, technologies and interconnected eco-engineering knowledge are decisive for the ‘pool of choices’ that practitioners have for choosing suitable sustainable management options. Although there is a need for more ‘ready to use’ sustainable engineering and technological solutions, our assessment revealed that usually economic drivers are more decisive for practitioners’ management choices. Thus, bio-economy and green finance initiatives such as 'green inclusive' societal business cases and payment schemes for ecosystem services that mobilize sustainable soil use need to be developed. Further, innovations to explore possibilities to shift away from "Business as Usual" and economic growth-oriented decision making are required. The need for development of operational, geospatial decision support tools, ICT tools for diverse locations/conditions, interactive assessments using soil and socio-economic databases (e.g. FADN) was expressed. Comparative tools are required to demonstrate soil management related disparity (differentiate between economic results and yields) that include cost-benefit information to support decision making.

Monitoring

To address the complexity related to data management with the increasing amount of data, concrete criteria and indicators of 'healthy soil' are required. Standardized indicators, measurement and mapping protocols will provide new monitoring technologies and efficient engagement methods (e.g. citizen science). Based on the FAIR principles (Findable, Accessible, Interoperable, Reusable), a coordinated organization, harmonization, standardization, storage, and exchange of soil research data needs to be promoted. In order to provide more data to researchers and stakeholders, remote and near surface sensing data applications (such as IoT and cart mounted) are needed to be developed. Regular monitoring and reporting of soil health and biodiversity are challenging areas of data management that are required to provide access to regional data for references.

Practice Oriented R&I

Efforts for research to cover all scales (field, farm, landscape, global, …) are needed and specific pedo-climatic zones (also smaller ones) need to be included. The pedologic data (soil maps) needs to be translated into agronomical 'ready to use' information for farmers and their advisors, while in urban areas ecosystem services of urban soils needs to be further explored and promoted. It is important to develop agro-ecological and regenerative management practices for a variety of local needs and conditions. For this, scientific/practical information needs to be shared in local languages to collate good and best practices in different specific contexts. Further, indigenous, local, and informal knowledge has to be integrated and disseminated to exchange this specific knowledge on a global level.

Policy and Awareness

It is important to establish robust, action-oriented soil protection policy frameworks on different political levels (local to EU level) to implement systemic intervention logics for policies to prevent downstream problems and to address root causes rather than symptoms. For this, an enabling environment for policy making and research funding needs to be created. In order to implement fair and functional incentives, regulations. Further, legal frameworks that promote gradual abandonment of damaging practices needs to be developed. Improved legal support to re-orient land management practices, integrated strategies to be implemented with only fragmented ownership are recommended. A priority lies in developing multi-level governance structures to develop EU standards and integration in EU commitments (e.g. Green City Accord, Local Green Deals) for improved EU transboundary cooperation. Concrete initiatives need to be developed to compensate private disadvantages in favour of public advantages. Binding, comprehensive and integrated legal frameworks are required to regulate data ownership and improve data standards for precision farming practices (organic farming and agroecology). In case of industrial land use, integrated assessments within industries should be carried out to promote application of sustainable R&I within large industries and their stakeholders.

For science-based policy support, overall strategic goals and implement frameworks for action need to be defined. The R&I experts reflected the importance to explore how soil policies can be aligned with sustainable soil management practices. Suitable scenario analysis tools for science-based policy development need to be developed to explore whole-of-government approaches for relevant policies. Thus, scientific knowledge has to be summarized and translated to be easily usable in multiple contexts, which in turn will provide independent advice based on scientific results. To use the outcomes of these tools and models in effective ways, programmatic combinations of actions such as assessments of overlaps and inconsistencies within policies within and between EU and member states, changes of EU agricultural policies (esp. the common agricultural policy CAP) needs to be promoted. Further, policy makers need to be mobilized by raising awareness on the importance of soil and land and related costs and benefits (e.g. through ecosystem services). To encourage them, appropriate rewarding mechanisms need to be developed.

A high need to increase capacities for raising awareness, training and education was observed. The actors emphasized the necessity to identify engagement barriers. This requires development of efficient soil risk communication strategies and implementation of push and pull based policies (i.e. prevent bad and promote good practice). Sustainable soil use certification for imported products needs to be developed. Further, there is a need to increase the willingness for change in particular with land owner and consumers. An effective way to engage people would be to explore how to make the subject interesting for people and how to engage people in citizen science. For example, the 'soil topic' into school/high school programmes can be incorporated, the SDGs and their relations to soils and land can be educated. This would promote a broad understanding of soils and land as limited resource and their role for our wellbeing and wealth. For Urban land use, the role of soil related issues for regenerative urban development needs to be underlined. Promotion of co-created city soil strategies is required.

3.3.2 Gaps per Soil Mission Objective

- **Mission Objective 1: Reduce land degradation relating to desertification**

For the understanding of soil degradation processes, there is a need to develop a proper definition of soil specific terms such as land degradation including proper definition of degraded and healthy urban soils as they are under-developed and somewhat obscured. To improve capacities for measuring soil degradation, easy measurable and cost-effective indicators and methods are required. Considerations need to be given to the development of performance indicators that take into account soil and land degradation. More research on identification of desertification and salinization endangered areas is required. Regarding urban soil use, spatial variability of urban soils in case of measuring land degradation should be taken into consideration. It is necessary to evaluate and map soil water holding capacity of urban soils. Inclusion of site-specific soil water retention capacity in spatial planning needs to be improved. The actors stated the need for improved assessment, forecasting and modelling approaches of drought under climate change.

Holistic and integrated research such as exploration of soil degrading processes along with the initial causes (drivers) on a holistic level and from a field to landscape scale is essential to understand the effects of increasing agricultural intensity. Effective water management is essential for sustainable soil management, hence, effects of climate change on soil hydrology need to be better assessed and understood. Behavioural assessment of perma-frost soils under climate change is required to evaluate impacts of the specific conditions depending on geographic settings. Special attention should be given to exploring the potential connections between soil degradation and human health.

Innovations for sustainable soil and land use are important. To reduce the potential long-term damages to soil resources, technical innovations such as develop and promote degradation preventive management is recommended. For example, the assessment related to agronomic effects of different conservation tillage methods in organic agriculture in arid regions (e.g. weed control, effects on soil health) is important to investigate the differences as well as challenges in implementing soil management practices. In addition, development of suitable conditions for more extensive land use in drier climate is recommended.

Development of restoration technologies that address a wide range of soil functions are beneficial to improve the conditions for agricultural activities. Therefore, new application of old techniques such as the use of cover crops adapted to specific areas, including their future climate, requires improvement. Further, the benefits and trade-offs of agroforestry and the role of diversification for soil health need to be further assessed. A need for more effective legislation to protect undisturbed soils and land is of vital importance for proper soil management. To avoid the use of undisturbed soils and promote the reuse of brownfields, the use of brownfields for greenhouses, urban development and (green) infrastructures need to be encouraged.

- **Mission Objective 2: Conserve and increase soil organic carbon stocks**

The overall results revealed a definite need for development of cost-effective and accurate measurement, reporting and verification systems and also, sufficient accuracy of land degradation identification methods needs to be ensured. In order to improve soil management practices, systematic and long-term soil organic carbon (SOC) monitoring is highly recommended. Therefore, identification and mapping of most critical hot spots of SOC losses (including in mineral soils) would be much more beneficial to prioritize interventions. This requires assessment of where and when SOC losses occur along with the potential variability of SOC as related to past land use. Also, emission factors for different soil types, pedoclimatic conditions and management options should be developed. Regarding land degradation, mapping of regional degradation risk factors like fire risks of forests is important. On the other hand, impact of building materials on SOC (e.g., SOC as a component of embodied carbon of wooden building materials) needs to be assessed. To evaluate the SOC storage potential in EU soils (general), assessment of the SOC restoration potential of climate smart sustainable soil management is required which can contribute to climate change mitigation at regional levels and at long term.

The actors formulated a great need for basic research on the cascading effects of SOC, the permanence/(ir-)reversibility of different management and remediation measures and assessment of the effects of climate change on soil organic matter degradation. Research needs to encompass a holistic approach to quantify the short- and long-term effects of SOC on yields, yield stability and soil health by exploring the short and long-term advantages and effects of SOC on water storage, yield and yield stability. Concrete business models for SOC restoration/conservation is required. It appears that comparative (short- and long-term) economic analyses of SOC effects in different local farming system scenarios (incl. small scale farms) are required to translate scientific results of SOC effects to economic effects and also to assess the impacts of incentives for carbon (C) sequestration on land prices.

Research management options for soil conservation and increasing soil C sequestration requires development of simple and reliable models or tools to evaluate SOC development at the plot/farm scale. The role of recycling crop residues/agro-industrial by-products for SOC needs to be explored. The assessment of the contribution of inorganic carbon to C-sequestration is also necessary to evaluate trade-offs between SOC sequestration. Moreover, improved understanding of C-capturing in grassland can contribute to mitigate the impacts of climate change, since grass is abundant in farming, urban and infrastructural areas. Technical innovations such as proposing crop choices for SOC increase in low rainfall environments, developing suitable cultivation techniques for management of organic soils used for agricultural production will help to meet the sustainable soil management approach. More actions are required to promote the use of cover crops and green manures. Besides, the use of urban organic waste for agriculture should be increased. Assessment of the role of forest tree species composition on C stock formation while integrating biodiversity (below & above ground) in SOC incentive schemes need to be fostered. To increase carbon storage in soils, concrete regional guidelines need to be developed to achieve higher productivity.

Institutions and governance on soil and land management for preserving and enhancing soil carbon sequestration can be improved by creating incentives for farmers to invest in carbon farming. For this, concrete subsidies for carbon sequestration and functional private-public schemes (together with financial institutions) have to be developed. In addition, incentives for C sequestration with access to land needs to be linked. It is also necessary to resolve ownership related motivation issues for promoting SOC (e.g. on rented land).

Appropriate measures such as promoting the use of non-peat alternatives for horticultural purposes (e.g. growing media) and restoration of peatland should be broadly taken up to preserve and manage existing SOC in peat lands. Further, policies and economic incentives need to be developed to efficiently support palidi-culture (rewetting peatlands).

- **Mission Objective 3: No net soil sealing and increase the reuse of urban soils**

To implement R&I approaches for sustainable soil and land management, an understanding of soils and urban land as limited resources needs to be established. For example, definitions of what 'healthy city soils' are and what their functions are, should be well-developed. Dissemination of information about human benefits of unsealed urban soils is highly recommended. There is a demand for developing methods with indicators to monitor soil health as well as to measure biodiversity in city soils. It is important to create adequate frame-works to account for the ecological impacts of soil sealing and mitigation actions (natural capital, “eco budg-eting”). To perform urban soil mapping that includes soil functions and services (multi-functionality index), suitable mapping tools and indicators that help evaluate soil multi-functionality need to be further devel-oped. In addition, assessment of how to weigh soil functions in spatial planning with relation to time needs to be encouraged. To enable research and development, there is a need for strategic requirements to pro-mote and advertise databases for land consumption and indicators for environmental effects of urban devel-opment at different scales. For this, development of soil and land indicators for Strategic Environmental As-sessment and urban planning are required.

There is a further need to develop tools to support no net soil sealing, urban soil reuse and soil functionality based territorial planning. Thus, adequate replacement options for soil sealing (e.g., nature-based solutions, permeable surfaces, etc.) are required that account for geospatial planning specificities and different require-ments for soil sealing prevention. Effective programs with improved integrated planning to prevent soil seal-ing need to be developed, while reduction in administrative fragmentation is required for this. Thus, changes in EU and national policies and actors' behaviour has to be promoted. To prevent/minimize soil sealing, inte-grated landscape management approaches that bring together key stakeholders for joint action (e.g. local Green Deals) need to be further developed, as well as improved. Optimization of road layout and mainte-nance for minimal impact and optimal logistics are necessary. The actors highlighted a need to develop re-gional or national eco-budgeting schemes that allow avoidance, mitigation or compensation of soil sealing impacts that must include improved acceptance of innovation and reduce reluctance from regulatory bodies. Hence, raising awareness about soil and urban greens maintenance is needed. Decision frameworks for local policy makers for evaluation of development plans compared to ecosystem services need to be formulated. In order to successfully minimize soil sealing, development of guidelines and targets for un-sealing and recy-cling of land such as guidelines for reusing and restoring soils from construction, infrastructure and industrial sites is required. Thus, legal support for green public procurement needs to be explored. New innovations and methods need to be developed to make new soils (constructed techno-sols) from excavated soils and organic wastes which may include use of composts for urban greenings, road works that will improve the use of collected green waste of cities and municipalities. Experiences with reuse of urban soils for agriculture to promote regenerative urban agriculture should be gathered.

Co-creation processes for soil restoration of formerly sealed land could be developed, including mapping of soil sealing problem and opportunity areas (including issues such as what to achieve by unsealing? what func-tions to restore? where is unsealing most effective?). Integrated landscape management approaches that bring together key stakeholders for joint action (e.g. local Green Deals) need to develop. For example: im-proving soil water infiltration and retention to help with flood and drought management. Engaging narratives that connect people with soils should be developed to bring people closer to the issue. For this, it is important to engage soil ambassadors. Also, people must be educated about the definition of No Net Land Take.

- **Mission Objective 4: Reduce soil pollution and enhance restoration**

A prominent problem regarding soil management is monitoring of soil pollution (including diffuse pollution). The assessment of soil type specific pollution factors is required to map severely or irreversibly polluted soils. Agro-ecological and regenerative management practices for agricultural and forest soils need to be further developed to improve knowledge on effects of agro-chemicals on soil health, soil organisms and its relation to soil functions (e.g. fertility). Such practices will improve knowledge on soil pollutants' effects on soil biota and soil functions. Efficient ecotoxicological assays need to be developed to analyse, in field, the effects of agro-chemicals and to broadly establish the use of bio-assays for ecotoxicological assessments. For all land uses, characterisation of emerging contaminants and their remediation, safe and controlled standards developed for soil contamination are also required. For example, the assessment of soil pollution threats from biochar and municipal composts. This will result in improved understanding of short- and long-term links between soil pollution and water pollution. Further, topics such as improvement of the knowledge of how micro plastic affects human health and the environment requires more attention.

Technical innovations are an integral part of sustainable management methods and technologies. In case of prevention, innovation in technical solutions such as developing pollution preventing sustainable management options is highly beneficial. Another initiative would be organizing interactive seminars with active practitioners on how soil health is essential for the future, which will contribute to enhance exchange among practitioners. The necessity of raising awareness and societal knowledge on existing and emerging soil contaminants, for example, raising awareness on pollutants in urban soil is emphasized. Moreover, it is required to explore how to transfer knowledge / instruments from large countries to small countries and vice versa for joint learning. Integrated pest management (IPM) guidelines dealing with soil borne diseases that includes sustainable alternatives to soil fumigants need to be developed. For urban soils, circular soil management in cities with combined urban infrastructures like cables and pipelines (sewer system / drinking water) and technologies to reduce diffuse contamination is recommended.

Regarding remediation approaches, special attention should be given to regenerative management practices. Particular efforts are required to promote technology and knowledge to avoid and to remediate soil pollution emphasizing remediation of heavy polluted areas. This may include prioritization of 'chemically-polluted' cultivated areas for restoration. Cost-effective technologies and nature-based solutions to remediate polluted soils and brownfields need to be developed. The use of composts and municipal organic waste for soil restoration of urban greens, road works etc. needs to be promoted. Hence, quality assurance for organic input materials should be mandatory. For city soils, nature-positive incentive schemes for urban and industrial development need to be promoted. The actors stated the need to establish brownfield taskforces (training, mentoring, practical examples, tips & tricks, commercial and economic tools) by developing systemic methods for temporary increase of soil functions and decontamination of brownfields. Besides, mitigation of anthropogenic events, strengthening the robustness of soil and land systems against external shocks is necessary. In case of city soils, integrating urban greens for mitigating extreme weather events (e.g. heat waves) and contribution to urban robustness is required for the management of urban and industrial soil use. The organization of redeveloping brownfields has to be centralized. The EU and national soil pollution prevention and remediation targets need to be well-defined. Thus, formulation of an EU Soil protection framework to create roadmaps for reaching no soil pollution by 2050 is essential. A definition of liability for emerging contaminations and funding schemes for implementation of remediation measures are required. Related to this, practitioners need to be educated on the active and future supports for soil protection.

- **Mission Objective 5: Prevent erosion**

Erosion models need to be developed, accounting for all kinds of erosion (rill-, inter-rill erosion, shallow landslides, etc.), including regular mapping of erosion prone and eroded areas. This calls in particular for research approaches that explore e.g. relationships between soil erosion, climate change and wildfires, relationships between soil erosion and land abandonment (esp. in mountain areas), or potential relationships between subsoil factors (e.g. compaction) and erosion. Further, these also should include assessment of erosion through reshaping environments (slopes, soil re-location), and trade-offs and synergies between soil erosion regulations and other ecosystem services.

Erosion prevention measures, specific to local needs and conditions, are required that include promotion of (agricultural) practices that prevents erosion on erosion-prone land. In addition, nature-based solutions in high erosion prone areas (adapted vegetation management) need to be encouraged. Practical tools for erosion control planning on the plot level with combined remote sensing and on-site measurements are required. Applicable solutions for reduced tillage in organic agriculture are needed to enhance erosion control approaches. For this, initiatives need to be deployed to promote cover crops by educating the people about the benefits of using cover crops and green manure. Besides, it is important to enhance urban greens to mitigate extreme weather events and related soil erosion. There is a further need for the development of management methods and technologies to restore heavily eroded lands. Also, it needs to be assessed how practitioners' willingness to change their management towards conservation methods can be promoted.

- **Mission Objective 6: Improve soil structure to enhance habitat quality for soil biota & crops**

Strengthening the role of soil health generally for all soil use types and raising awareness on relationships between soil biology and soil quality are very important aspects for enhancing habitat quality for soil biota and crops. This requires implementation of soil quality and biodiversity monitoring by developing harmonized bio-indicators and measurement protocols. It is important to differentiate between economic results, yields, work effort and external inputs (e.g. energy). Soil health indicators and benchmark values that can be applied in various soil use scenarios should be developed. Soil quality indicators with legal frameworks for soil-based production strategies need to be linked, which include soil structure in Nature Based Solution monitoring schemes and soil structure and quality indicators in key indices (e.g. Singapore Cities Biodiversity Index).

The actors depicted the need for improving the basic and specific understanding of soil biological and ecological processes and dynamics. To improve knowledge on links between soil management practices and soil borne diseases, mapping and assessing soilborne disease, or parasitic nematode pressure in producing areas for differential assessment are recommended. The urgent R&I needs stated are assessing potential impacts of spatial (in-filed) variability of soils on wider patterns (yield, pathogens, soil functions), assessing the role of antibiotics (including glyphosate) and of antibiotic resistant pathogens for soil biodiversity and assessing the soil ecological status of industrial sites and how it can be improved. Links between agricultural practices, soil health, soil ecology and crop yields (incl. nutrient and water supply) need to be evaluated. Moreover, the role of compost addition on soil biota, soil and food quality should be assessed. Further, the role of recycling crop debris and agro-industrial by-products for soil health needs to be considered. Improvement regarding the understanding on relationships between biochar and soil health is also needed. In addition, soil health remediation measures should be promoted.

Innovative bridges between the nature sector and other sectors (e.g. agricultural, urban) is essential for improving soil management practices. Applicable agroecological concepts and tools including agroecological and regenerative management practices for a variety of local needs and conditions need to be adapted. A great need for developing concrete soil health management guidelines for practitioners is stated. Formulation of concrete guidelines for farmers to improve soil structure with specific solutions for different scales of farming (small to large scale) and development of decision support tools for designing soil health promoting crop rotations have been emphasized. Site-specific implementation technology for soil health and biodiversity promoting management practices are required. This may boost the use of urban organic waste for agriculture. Moreover, these management practices need to develop and implement conversation tillage management without pesticide use. In addition, these management approaches will lead to reduction of total nitrogen deposition on nature areas and reduction of the use and dependence on P fertilizers. It is necessary to provide an adequate legal classification of 'agroforestry' between agriculture and forestry. On the other hand, methods to stimulate biodiversity on temporary unused land or brownfields (e.g. urban, industrial) need to be formulated. Also, assessment of how the ecological value of industrial soils can be improved based on the SDGs is needed.

- **Mission Objective 7: Reduce the EU global footprint on soils**

The actors highlighted the underestimated importance of the global footprint and also suggested to distinguish between ecological and economic risks and social impacts. At present there appears to be a lack of clear definition of the global footprint on soils (for different land uses) that account for the multi-functionality of soils. Current and anticipated gaps related to the global footprint of European activities include a holistic approach of the soil footprint and clear indicators that go beyond land consumption. The time needed for regeneration of various forms of soil degradation needs to be integrated. In addition, current vs. potential soil quality and related production potential should be evaluated. There is a need to consider regional and global differences of soil capacities and footprints. In particular, the EU global footprint on urban soils in assessments needs to be included. For example, private gardens and parks need to be included in global footprint calculations. Another important aspect would be learning from other footprint examples for the EU footprint on soils (incl. which indicators to choose). A soil footprint per person needs to be well-defined and comparable on spatial scales. Moreover, homogenous ontologies for soil footprints need to be developed.

The actors proposed to apply holistic agro-ecosystem modelling methodologies to reduce the global footprint. Clear threshold values for a safe operation space (i.e. the baring capacity of soils) and risk mitigation need to be established and supported through sufficient data collection. It is necessary to ensure reliability of data platforms (on EU and member state level). Effective measures to prevent biases in monitoring approaches and state level statements are required. Remote sensing technology needs to be promoted for global footprint assessment (e.g. biomass production). Dynamic soil footprint data models to determine soil health changes need to be established to improve interoperability of datasets and models. To engage practitioners and stakeholders in the assessment of global soil footprints, Citizens Science approaches for soil footprint assessments need to be developed.

The technical understanding of direct and indirect impacts on the global footprint need to be extended. Further, research is required to investigate positive and negative relationships between the land productivity index and soil health. The impact of carbon cycles on the global footprint on soils needs to be evaluated. Requirements for R&I include clear assessment and modelling of the impacts of biofuel imports and assessment of the influence of land abandonment (economic and regulatory influence) on the footprint. Foresight scenarios to identify future implications and possibilities for change are required. For this, machine learning for data processing and visualization can be utilized which in turn will provide more and easily accessible data about our soil and land footprint outside the EU.

There is a need for assessing the impact of policies and measures on the global soil footprint at multiple levels. This also includes the assessment of policy trade-offs related to the global footprint and development of mitigation strategies. More specifically, acceptable risks, soil quality thresholds and solution pathways need to be developed and/or standardized. It is also necessary to compare sustainability of imports versus EU internal production to way of soil footprint impacts for decision-making. Thus, the global footprint for regulations and policies (e.g. CAP) should be taken under consideration that account for international competition for resources, soil and water. To create balance in import-export cycles, strengthening the sustainability of the supply chains and avoiding of price fluctuations due to speculation are recommended. More research is necessary to assess how to balance imports and exports due to regional suitability for particular products. This requires regulation and reduction in imports that lead to soil and land degradation and deforestation. Management changes that reduce the soil footprint should be rewarded, e.g. through the CAP, or payments for Ecosystem Services. In case of urban soils, reduction of use of primary building materials and non-sustainable resources is encouraged. Further, soil footprint related standards for the import of renewable building materials and biofuels need to be developed.

Consumption pattern's (e.g. diets, building materials) impact on the global soil footprint must be linked to good practices. The general approach for this would be to create consumer awareness, reduce resource consumption, to assess overall quantity of the demand combined with product and production quality, to assess how to mitigate for/reduce high demands for high impact products and as a final point, to assess how to reduce the footprint in the different regions. In addition, a strong need to establish multi-stakeholder collaborations for efficient use of resources and risk mitigation was stated. This establishment requires development of resource efficient practices that connect soils with circular economy.

- **Mission Objective 8: Increase soil literacy in society across MS**

Increasing capacities for raising awareness, training and education on the central role of soils for human activities and their wellbeing is essential to build the connection between people, soils and land. To re-establish the connection between rural and urban areas, it is required to explore how to make the subject interesting for people and how to engage people in citizen science. Further engagement barriers need to be identified to improve the connection. It also requires assessment of how to reach consumers and improve their consumption behaviour. A broad understanding of the effects of one's choices that assigns values to culture, biodiversity, land degradation and natural resources to improve the understanding of trade flows and trade-offs needs to be promoted. Of specific concern is an apparent lack of understanding of soils and land as limited resource. The actors suggested to improve the understanding of resource security as an important driver of economic long-term stability. Moreover, for city soils, it is important to highlight the role of soil related issues for regenerative urban development by promoting co-created city soil strategies and multi-functional urban greening approaches in public and private spaces to promote soil health. Raising awareness is required to establish that the different soil types and qualities should be considered for soil use decisions in urban planning. To develop narratives that connect people with soils, 'story telling' as a tool can be promoted and used to strengthen the collective memory. Raising awareness on contaminated sites that are not remediated (e.g. through art projects) is required to ensure that the stakeholders and actors realize the need for adaptation and increase their willingness for adaptation (esp. land owners, consumers).

There is an apparent deficit of soil literacy and this can be addressed by developing efficient approaches for increasing soil literacy and for soil risk communication. To provide soil health related education, it is important to establish genuine education approaches on the importance of soil and their properties at primary, secondary, and university levels in all EU member states. Improved education and awareness raising resources are required to educate advisors and practitioners on soil topics. Simple tools need to be developed for policy makers to explain 'soil & land issues'. People need to be educated about the SDGs and their relationships to soils and land. Also, they need education on soil health indicators and soil health promoting management options (esp. biological parameters). For this, the perception of biological soil health issues (e.g. pest problems and beneficial organisms) has to be promoted.

The increase in sharing, communication, dissemination and transfer of good practices, tools and skills with concrete messages and options for action will enable interactions between farmers, foresters and researchers, to promote a basic understanding of the benefits of soil health measures. For this, organizing interactive seminars with active practitioners on how soil health is essential for the future. In case of urban land use, urban farming has to be promoted as a tool for education and raising awareness. It needs to be ensured that soil related questions are part of discussions & activities on urban transformation.

Improvement of broad soil knowledge amongst researchers and efficient training on interdisciplinary methods is essential. For this, citizen science projects can be performed and also schools (e.g. COOLSCHOOL Project) can be involved. For this, the acknowledgment of outreach efforts within scientific projects and career success criteria needs to be increased substantially. National and integrated policies to enhance soil literacy in the society (education, communication, training, awareness, participative science and observatories) need to be formulated. Also, developing sustainable soil use certification for imported products is recommended. The process of developing these policies must include the engagement of soil ambassadors.

3.3.3 Shared vs. specific knowledge gaps between the Soil Mission Objectives

The different gaps previously presented were identified considering each Mission Objective separately. It appears that some of the gaps are common to several or all 8 Mission Objectives whereas others are dedicated and specific to only one objective.

A first common gap identified is the lack of **clear definitions and ontologies** for "soil health" but also for several Mission Objective related terms such as degraded land, soil sealing, or soil footprint. Clear definitions and ontologies are urgently needed for action, to describe and agree on what we are talking about and what should be measured.

The next common gap is the need of **agreed, shared and harmonized indicators** (and if possible multifunctional ones) for all Mission Objectives except for MO2 (dedicated to the conservation and increase of soil organic stocks). Those indicators should be accompanied by **interpretation values** (e.g. thresholds, normal operating ranges) depending on soil type, land use, climate, etc. to support adequate decision making.

Related to this, there is a need to identify and/or develop cost effective methods for measuring/calculating those indicators to be able to implement **large monitoring programmes** (e.g. using remote sensing, citizen science, on field sensors) to collect relevant data. Data should preferably be open and accessible in shared platforms (see FAIR principles) (identified for MO7: Reduce the EU global Footprint).

Another gap identified for all Mission Objectives (except for MO7 and MO8: Increase soil literacy in society) is the **need for maps** to identify at small and large scales areas impacted by degradation or pollution (including diffuse forms of contamination), hot spots of biodiversity and carbon stocks or lacks, eroded land or land susceptible to erosion. Such maps are needed for decision making, actions as for remediation, protection, land planning and raising awareness.

Development of appropriate models, at different scales, to forecast soil evolution (either degradation or remediation) is also identified as a gap for several Mission Objectives as for soil degradation/ pollution/erosion, sequestration potential and emission of carbon dioxide in soils (and other Greenhouse gases), prevision of droughts and floods, biological activity, etc., but also to calculate soil footprints. Consideration of time scales is of great interest to support decision making (e.g. how quick will soil recover after a degradation?). The development of digital twins is suggested to test solutions.

Several Mission Objectives linked to land degradation (whatever the type of degradation: salinization, desertification, soil sealing, pollution, erosion) and even footprint assessment call for the **reuse/the recycling of land and soils**, meaning that those areas should be considered as a resource to be reused (using proper remediation techniques) and not abandoned. This is also to be considered in footprint assessment as the recycling of degraded land or soils will reduce the impact of production and/or prevent fertile soils to be sealed for example. Thus, it is also requested to **identify and promote restoration/remediation techniques** (if possible nature-based solutions) **and agroecological practices** for all land use types. The development of agroforestry and reduced tillage, the introduction of cover crops, decontamination techniques, de-sealing operations, soil amendments (e.g. compost) are seen as valuable options. **Economical valuations** of all those solutions should be undertaken to push cost effective ones and innovations should be developed and promoted to lower their prices. Research is also needed to identify initiatives and business models for land users/owners to implement such solutions (e.g. to develop carbon farming to improve soil health).

Finally, for several Mission Objectives a **link with other issues** was also underlined and gaps were identified concerning connections between land or soil with human health, water cycle/quality and biodiversity.

Concerning more **specific gaps**, the following where identified:

- Impacts of fires on soil carbon and on erosion need further studies

- Organic soils such as permafrost and peat are identified as pieces of land to be studied and protected to prevent degradation (since they play important roles in climate regulation). Impacts of forest management on soil carbon deserves more research. Note that inorganic soil carbon should be more considered.
- Urban and industrial soils are seen as less investigated areas and research is needed to improve our knowledge on their role for (i) biodiversity preservation/conservation, (ii) local regulation of climate, (iii) building of new soils (technosoils) and ecosystems, (iv) de-sealing, un-sealing and remediation techniques. Regarding these, one important issue is to identify which functions should be restored, including the level of restoration as this may impact time and money needed for such actions.
- Direct and indirect effects of the use of land and soils must be considered when developing soil footprints (e.g. bioenergy policies have direct and indirect effects on land use and land use changes that need be integrated in a soil footprint). That implies that management methods should be applied at local/regional scale but should also considered on landscape and global scales.

4. SYNTHESIS AND DISCUSSION

4.1 Limitations of this research

The here performed key-word based literature search was limited to Scopus-indexed scientific journals. Although our search strategy is robust for peer-reviewed scientific journal articles, other publishing formats such as conference papers, books, book chapters, non-digitalized articles, grey literature, reports, patents, etc., may be underrepresented or not included in the used data base. In summary, non-scientific studies, or non-peer-reviewed scientific articles are not present in the inventory of this literature review. Nonetheless, important reports and information have been incorporated by the project consortium internal experts, who analysed and processed the collected information of their respective area of expertise.

Further, the Scopus database is biased towards journals that publish in English language (Sweileh et al. 2017), as well as this study was generally limited to articles published in English, in order to avoid a bias of used literature towards publishing languages that are represented within the project consortium. Thus, output from non-English journals and articles is not reflected in the literature review, which may be of particular importance for publications in early years, when English was not yet broadly established as a global standard for scientific publishing. Nonetheless, we consider the used data basis for this review article as representative for the overall trends within the scientific field, since it includes major scientific journals that reflect up-to-date developments through their published articles. We want to point out in particular, that absolute numbers of identified articles should be regarded carefully and rather seen as trends when comparing different focus topics with each other. They do not reflect absolute numbers of published articles.

4.2 Overcoming contextual gaps to reach the Mission Objectives

The pathway to the targeted impacts and Mission Objectives is unknown, uncertain, complex and paved by many blocking factors, missing elements and pitfalls that should be anticipated and overcome. These blocking factors might be located at any step of the pathways. R&I projects, **Living Labs and Lighthouses** enable the generation of new knowledge answering to R&I gaps and actionable by interested stakeholders. However, to generate outcomes and impacts, it is necessary to create the conditions and overcome contextual gaps (new technologies, new markets, new user contexts, new regulation and policies...) to foster innovation. The role of emergent stakeholders and of incumbents along the pathway and especially when R&I results have to be taken up, transformed, used and diffused remains crucial in the impact generating process. Another main issue in achieving the expected objectives is the ability of actors to upscale the local solutions.

Some of the R&I gaps identified in this report are related to the creation of new knowledge through R&I activities but other **gaps are related to the socio-technical context.** In this part, we will briefly underline some of these gaps, that should not be overlooked.

For all Mission Objectives the need to **raise awareness** on soils and **increase soil literacy** was underlined and stressed in several workshops and the survey, including communication on all roles of soils: food and water security, climate regulation, links to human health (reservoir of antibiotics but also source of contaminants), the fact that soils give shelter to numerous forms of life, etc. Narratives about soils and success stories should be developed to explain how and why soil is important and make all the needed changes (e.g. in agricultural practices, in land consumption) more acceptable for stakeholders. Improving communication among the different partners of LL and actors of the value chain will enable to translate scientific results into economic effects and other types of impacts. Of course, developing and conducting such targeted communication and dissemination should be undertaken to identify stakeholders' and consumers' motivations and the proper and efficient messages to be delivered to reconnect people to soil. Establishing a soil footprint is seen a way to better consider soil in daily consumption.

Improving the **coordination of actors and activities** of the socio-technical system will increase sharing communication, dissemination and transfer of research results and good practices. This might be done by connecting LL, creating communities of practices, connecting rural and urban areas, but also farmers, foresters and researchers.

Raising attention on soils may also pass-through children by teaching more soil in **school programs** or through **artistic initiatives and events** as land and soils always attract children and inspire mankind. Having soil ambassadors is essential. Teaching activities and transferring knowledge to users might also be done through the creation of farmer-field schools and demo farms.

It also claimed to develop **guidelines and decision support tools** for stakeholders to help soil management and soil restoration. This is needed to identify, promote and transfer the relevant knowledge and techniques to the users. Such guides and tools must be developed for all Mission Objectives: existing methods and practices to manage agricultural and forest land, to restore degraded land (whatever the degradation), to drive soil carbon and soil biodiversity, to prevent erosion and reduce pollution, to stop soil sealing and push de-sealing techniques... Guides and tools should be developed keeping in mind that not all stakeholders have the same knowledge and link to soils (e.g. farmers, policy makers, local planers, citizens) and that implies that different levels of complexity and explanations are requested. Several documents and tools have to be developed depending on the targeted audience and co-construct with them.

To promote awareness raising and transfer of knowledge the **career success factors of scientists** should be revised as the academic recognition of a researcher is generally based on its publications and not on the development of guides, standards, tools, communication, or in its television appearance or newspaper articles. The success criteria and the impact of research should be judged differently!

4.3 Policies & governance

The HE Mission 'A Soil Deal for Europe' is a new instrument implemented to directly and intentionally support the transition towards healthy soils by 2030. To reach this broad objective and the underlying eight Soil Mission Objectives, the Soil Mission should transcend the boundaries of established soil and land policies at EU, national and regional levels. This approach should be broader than Science Technology and Innovation (STI) funding and policies fostering technological innovations for competitive purposes and should encompass more societally beneficial STI activities supported by the state and R&I performing actors. **Living Labs and Lighthouses** supported by the Soil Mission constitute relevant bottom-up experimentation and learning tools that include a broad range of actors (producers, consumers, public research actors, farmers, foresters etc.) for inducing system transformations. Steering R&I activities and stabilizing new trajectories towards the Soil Mission Objectives will require a coherent mix of STI instruments and non-STI policy instruments, bottom-up and top-down initiatives. STI policy instruments should mix supply-side instruments (R&I funding initiatives) and demand-side instruments (public procurement for innovation) and address the various steps of the innovation process (R&I, demonstration, market creation and other forms of generalization mechanisms such as the creation of new networks and alliances). Non-STI instruments include elements such as regulation, price mechanisms and public procurement. Regulation is particularly important to overcome important blocking factors related to technological and market issues. It is less the creation of new instruments that is crucial, rather than the coordination of existing instruments in a policy mix that should be compatible with the objectives of the HE Mission.

The governance of Mission-oriented policies and thus the coordination between existing policies at different levels (from local to EU) or horizontally (combination of STI policies with sectorial policies related to soils and land) constitute an important challenge. The policy actors responsible for the HE Mission should develop capacities and coordination mechanisms to organize the appropriate policy mix and governance structure. These policy mixes should be modified and adapted to the changing environment and the transformation pathway. Thus, Soil Mission orientation calls for policy experimentations: new types of regulatory processes, new institutions and new governance approaches etc. New capacities are needed to define the appropriate governance structures, policy mixes and implementation mechanisms. To ensure that the activities, undertaken by researchers and the various other stakeholders involved in Soil Mission-oriented policies, contribute to the expected objectives, new modes of monitoring and steering activities should be carried out. Steering activities towards a given direction will require to develop and implement tools for real-time management of Living Labs, R&I projects and Soil Mission-Oriented programs.

There are already several policy instruments and strategies in the EU that have a direct link to sustainable soil and land management and to one or several Mission Objectives. The European Green Deal (EGD) seeks to achieve climate-neutrality by 2050 and presents a roadmap for making the EU's economy sustainable. Among others the EGD aims to revert biodiversity loss, cut pollution and to reduce the environmental and climate footprint of the EU food system. The EGD Roadmap (COM (2019)640 final[2]) includes the revision of several legislative measures to align them with the objectives of the Green Deal and proposes the introduction of new strategies and legislation related to sustainable soil and land management. The EU Farm to Fork strategy, the Biodiversity Strategy for 2030, the Soil Strategy, the new Forest strategy, and the Zero pollution action plan are important elements of the European Green Deal and the implementation of the UN Sustainable Development Goals. These strategies and the introduction of new legislation and action plans proposed in the strategies (e.g. Action plan for integrated nutrient management, revision of Sustainable Use of Pesticides Directive, Nature Restoration Law, Urban Greening Plans and the Soil Health Law) are essential to foster changes in sustainable soil and land management and to achieve the goals of the HE Mission. It is highlighted that a coherent policy framework and better coordination between existing and upcoming policies from EU to local level is needed. Thus, inconsistencies between policies at European and Member State level should be analyzed and local and regional authorities should be empowered to implement actions (e.g. the Green Deal Going Local initiative[3]).

Within the new framework of the Common Agriculture Policy (CAP), which is the central element of incentives for European farmers to implement sustainable soil management, Member States are already required to implement the New CAP post-2020 in line with the Target of the European Green Deal. This includes for example new standards for good agricultural and environmental condition, eco-schemes and agri-environment-climate commitments. However, implementation at Member State level varies greatly, both in terms of the design of mandatory measures within the framework of conditionality, the number and coverage of measures and, more generally, the financial resources and the budget share for particularly effective measures. Barriers to the transition to more sustainable soil management practices should be identified at different levels and for different soil actors. Research should be developed at local level and national/EU level to identify these barriers and propose adapted options such as incentives linked to agricultural policy (CAP), new business models (e.g. carbon farming), insurance, training and advice.

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[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2

[3] https://cor.europa.eu/de/engage/Pages/green-deal.aspx

The Biodiversity Strategy for 2030 (COM2020/380 final)[4] and the Soil Strategy for 2030 (SWD(2021) 323 final)[5] will also play a key role in addressing the Mission Objectives, by developing a set of different binding and voluntary policy instruments. The upcoming Nature Restoration Law, for example, seeks to limit soil sealing and urban sprawl, tackle pollution and to restoring soil ecosystems, in particular carbon-rich soils. The Soil Strategy defines very specific actions to be conducted in the coming years. These include for example, members states setting by 2023 their own ambitious national, regional and local targets to reduce net land take by 2030, legally binding provisions to identify, register and remediate contaminated sites, provide EU-wide harmonized monitoring of the evolution in soil organic carbon content and carbon stocks, present a legislative proposal on carbon removal certification and develop a Soil Health Law with legally binding provisions. Importantly the Soil Strategy strives for better coherence and stronger synergies between EU policies as well as the Rio Conventions highlighting the synergies between soil health, climate and biodiversity. The extent to which these strategies will be successful and to realize their full potential depends on cooperation between different sectorial policies and actors, political will, actual implementation at member state level and financial support.

4.4 Next steps and recommendations

Socio-economic and governance gaps were the main gaps identified during our process but we restricted our literature review to soil and land. Extending our research by including other domains as water or biodiversity may reveal exiting socio-economic and governance knowledge adaptable to soil and land management, but not yet tested in these fields. It would be relevant to consider such work in the future.

Note that among all identified gaps, some are already covered by ongoing or upcoming Horizon Europe Framework Programme (HORIZON) calls. Calls on indicators, monitoring, data and knowledge collection and sharing, living labs development in relation to different land uses and soil management options were launched to fill parts of those gaps. The European Joint Programme Co-fund on Agricultural Soil Management (EJP SOIL) will also further contribute to increase our knowledge on several issues, including socio-economic and governance aspects.

The results of the validation workshop and this deliverable will be the main input for the drafting of the roadmap in the SMS project. As a first step, impact pathway graphics will be developed for each HE Mission Objective 'A Soil Deal for Europe', based on the Horizon Europe project impact pathway. These graphics will provide a logic and understandable 'narrative' of how the expected outcomes and impacts could be achieved. The graphic overview will serve as an early input to the European Commission and the HE Mission for the upcoming work programme (publication end 2022).

As we identified many R&I gaps in this deliverable, a group of experts will work on merging/regrouping gaps together to simplify the development of the roadmap. In a next step, a technical sheet will be developed for each of the identified and merged knowledge gaps, including e.g. linkage to the group of key actors, land use sector, regional scope, trade-offs and synergies. These technical sheets will be validated by a dedicated expert group. The final roadmap will be published by the end of October on the project website. A key-approach towards the development of the roadmap is the application of actor engagement mechanisms by developing a common language – the ontology. Thus, a domain ontology will also be delivered at the end of the SMS project, based on the common understanding achieved between the scientists and actors engaged in R&I on soil and land management.

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[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

LITERATURE

Brils J., Ellen G.J., Maring L., Koopman J., Anderiesse M., van Dongen M., Ittner S., Naumann S., Prokop G., Bispo A., 2021. Actor engagement guide. SMS deliverable 3.3 (public)

EC, 2021. A Soil Deal for Europe: 100 Living Labs and Lighthouses to lead the transition towards healthy soils by 2030. Implementation Plan. Directorate-General for Research and Innovation, European Commission. Internal working document of the European Commission

EL Akkari M., Sandoval M., Le Perchec S., Réchauchère O., 2018. Textual Analysis of Published Research Articles on the Environmental Impacts of Land-Use Change

Kassai P., Francis N., Rafiul Hashar M., Farkas-Iványi K., Löbmann M., 2022. Factsheet based overview of soil and land related recent H2020 projects, European R&I institutions and Living Labs. SMS deliverable 2.3 (confidential)

László P., Kassai P., Farkas-Iványi K., 2022. Detailed actor analysis. SMS deliverable 3.2 (confidential)

Löbmann M., Helming K., 2021. Reflection analysis on very urgent R&I gaps related to sustainable soil and land management. SMS deliverable 2.1 (confidential)

Löbmann M., Maring L., Prokop G., Brils J., Bender J., Bispo A., Helming K., 2022. Systems knowledge for sustainable soil and land management. Science of the Total Environment, 153389.

Maring L., Ellen G.J., Brils J., 2022. Report on prioritization of actor needs and criteria for Living Lab/Lighthouse identification. SMS deliverable 3.4 (public)

Reboud X., Fournier D., Leiser H., Tatry M.-V., Barbier M., Cointet J.-P., 2012. Analyse lexicale du corpus bibliométrique « agroécologie » au sens restreint, In: Inra, ed. Rapport INRA du chantier Agro-écologie.

Réchauchère O., Bispo A., Gabrielle B., Makowski D., 2018. Sustainable Agriculture Reviews 30: Environmental Impact of Land Use Change in Agricultural Systems. Springer.

Sandoval M., Tarot C., 2014. Etude bibliométrique sur les transitions nutritionnelles. Les transitions nutritionnelles dans la littérature scientifique internationale. Méthodologie (démarche d'exploration) et résultats d'analyses, Rapport de l'étude bibliométrique sur l'axe 6 du MP GloFoodS.

Sweileh W., Al-Jabi S., Zyoud S., Shraim N., Anayah F., Sawalha A., AbuTaha A., 2019. Bibliometric analysis of global publications in medication adherence (1900–2017), International Journal of Pharmacy Practice, Volume 27, Issue 2, April 2019, Pages 112–120

Tancoigne E., Barbier M., Cointet J.-P., Richard G., 2014. Les services écosystémiques dans la littérature scientifique : démarche d'exploration et résultats d'analyse.

ANNEX I: METHODOLOGY – HE Mission Objectives and targets

Table 7: HE Mission Objectives and related targets and soil health indicators
Source: The HE Mission "A soil deal for Europe" (EC, 2021 page 16-17)

Mission Goal: 100 living labs and lighthouses to lead the transition towards healthy soils by 2030			
Objectives	Mission targets in line with EU and global commitments	Baseline (see 8.A)	Soil health indicators
1.Reduce land degradation relating to desertification	T 1.1: Halt desertification to help achieve land degradation neutrality and start restoration --- In line with SDG 15.3	25% of land in Southern, Central and Eastern Europe at risk of desertification.	All eight soil health indicators
2.Conserve and increase soil organic carbon stocks	T 2.1: Current carbon concentration losses on cultivated land (0.5% per year) are reversed to an increase by 0.1-0.4% per year T 2.2: the area of peatlands and wetlands losing carbon is reduced and the natural sink is significantly increased to help meet GHG reduction targets by 2030 and the Climate law goal by 2050. --- In line with the Fit for 55 Climate Energy Package (Climate Law, revised LULUCF regulation) and the Paris Agreement 4 per mille initiative.	Area of land with low and declining carbon stocks = 23%. Area of degraded peatland = 4.8%	Soil organic carbon stock Vegetation cover
3.No net soil sealing and increase the reuse of urban soils	T 3.1: increase urban recycling of land beyond 13% and switch from 2.4% to no net soil sealing as a contribution towards meeting the target of no net land take by 2050. --- In line with Roadmap to a resource efficient Europe, and Biodiversity Strategy including upcoming nature restoration targets	Area of land affected by soil sealing = about <1% of EU, but can be as high as 2.4%, Current rate of recycling of urban land for development: 13%	Soil structure (incl. soil bulk density, absence of soil sealing, erosion and water infiltration) Vegetation cover
4.Reduce soil pollution and enhance restoration	T 4.1: reduce the overall use and risk of chemical pesticides by 50% and the use of more hazardous pesticides by 50% T 4.2 reducing fertilizer use by at least 20% T 4.3: reduce nutrient losses by at least 50% T 4.4: 25% of land under organic farming T 4.5: Reduce microplastics released to soils to meet 30% target of zero pollution action plan T.4.6 Halt and reduce secondary Salinization All to be achieved by 2030 to contribute to meeting the target by 2050 that soil pollution is reduced to levels no longer considered harmful to health and natural ecosystems. --- In line with the Biodiversity strategy, the Farm to Fork Strategy and the Zero Pollution Action plan.	27% - 31% of land with excess nutrient pollution Soil contamination: 2.5% (non-agricultural), 21% (conventional arable), ca. 40-80% of land from atmospheric deposition depending on the pollutant. Farmland under organic agriculture: 8.5% (2019)	Presence of soil pollutants, excess nutrients and salts

5.Prevent erosion	T 5.1: reduce the area of land currently affected by unsustainable erosion from 25% to sustainable levels -- In line with the Roadmap to a resource efficient Europe	Area of land with unsustainable soil water erosion is 25%, with 70% of this being agricultural land.	Soil structure, absence of soil sealing, erosion and water infiltration Vegetation cover Landscape heterogeneity Forest cover
6.Improve soil structure to enhance habitat quality for soil biota and crops	T 6.1: Reduce compaction of soils to go significantly below current levels of 23% - 33% -- As for forest soils: in line with the new EU Forest Strategy	Area of land with critical levels of soil compaction = 23-33%, 7% of which is outside agricultural area.	Soil structure, absence of soil sealing, erosion and water infiltration. Vegetation cover Landscape heterogeneity
7.Reduce the EU global footprint on soils	T 7.1: Establish the EU's global soil footprint in line with international standards T 7.2: The impact of EU's food, timber and biomass imports on land degradation elsewhere is significantly reduced without creating trade-offs -- In line with the Zero Pollution Action Plan	Baseline to be created by mission activities	Food, feed and fibre imports leading to land degradation and deforestation
8.Increase soil literacy in society across Member States	T. 8.1: awareness of the societal role and value of soil is increased amongst EU citizens, including in key stakeholder groups, and policy makers T. 8.2: soil health is firmly embedded in schools and educational curricula, to enable citizens' behavioural change towards the adoption of sustainable practices both individually and collectively. T 8.3: citizen involvement in soil and land-related issues is improved at all levels T 8.4: practitioners and stakeholders have access to appropriate information and training to improve skills and to support the adoption of sustainable land management practices.		All eight indicators (on a long term)

ANNEX II: METHODOLOGY – Detailed search request for the literature review

A keyword-based stocktaking of soil and land management related R&I literature has been conducted in Scopus. Scopus is an abstract and citation database of peer-reviewed literature and web sources with tools to track, analyse, and visualize research. The objective was to inventory all existing articles that contain key words related to i) the respective societal challenges (columns), combined with ii) the respective knowledge domains (rows).

Terms describing the knowledge domains and the societal challenges were combined in an iterative manner until best performance was obtained (Table 8 and Table 9). Given the existence of numerous synonyms for the concept of the different societal challenges and knowledge domains, the search term was constructed by crossing, one by one, the different synonyms existing (and variations in their spelling). Construction of the list of synonyms was based on different studies (Tancoigne et al., 2014; Pellerin et al., 2019; Zhang et al., 2019; Oliveira, 2020). Searches were performed using exclusively English search terms. Articles containing the search terms in their titles or keywords were filtered. So as to not overlook the characteristic of action/change of the societal challenges (i.e. “increase”, “improve”, “adapt”, “reduce” and “mitigate”), action verbs are integrated in the search strings. Search requests are presented in Table 8 and Table 9 per societal challenge and per knowledge domain. An example for a specific cell of the knowledge matrix is also given in Table 10. The search is limited to journal articles that were published before the year 2020 included.

Among all articles identified, a screening process was conducted in order to select only relevant articles. Due to limited time resources, articles from cells with more than 50 articles were not reviewed, some cells have more than 5 000 articles. Only cells of the SMS knowledge matrix containing less than 50 articles were screened. Per cell, a team of reviewers specialised on a given topic was constituted. In regards to the topic of a particular cell, the reviewers assessed the relevance of each article via its title and abstract. Articles which were not considered relevant were either removed or relocated to a more appropriate cell. In some cases, some articles outside of Scopus which our experts identified as relevant were also added in the SMS corpus.

Each collected article in the database contains the following references:

- Title, abstract, keywords, year of publication, authors
- Countries and institutions from where the article was published
- Knowledge domains studied (in relation to the extended SMS knowledge matrix)
- Societal challenge studied (in relation to the extended SMS knowledge matrix)

Increase biomass production	(TITLE(("soil" OR "land") AND (((increas* OR enhanc* OR reinforc* OR support*)) W/5 (food OR energy OR "crop" OR wood OR "yield" OR timber))) OR KEY(("soil" OR "land") AND (((increas* OR enhanc* OR reinforc* OR support*)) W/5 (food OR energy OR "crop" OR wood OR "yield" OR timber))))
Mitigate land take	(TITLE(("soil" OR "land") AND ((seal* OR unseal* OR urbanizat* OR urbanisat* OR "land take" OR "land uptake" OR artificiali* OR "urban sprawl" OR "brownfield") W/5 ("no net" OR mitigat* OR attenuat* OR reduce* OR reduction OR avoid* OR compensat* OR stop* OR regulat* OR limit* OR protect* OR combat* OR tackl* OR prevent* OR remediat* OR recultivation OR redevelopment))) OR KEY(("soil" OR "land") AND ((seal* OR unseal* OR urbanizat* OR urbanisat* OR "land take" OR "land uptake" OR artificiali* OR "urban sprawl" OR "brownfield") W/5 ("no net" OR mitigat* OR attenuat* OR reduce* OR reduction OR avoid* OR compensat* OR stop* OR regulat* OR limit* OR protect* OR combat* OR tackl* OR prevent* OR remediat* OR recultivation OR redevelopment))))
Mitigate climate change	(TITLE(("soil" OR "land") AND (("climate change" OR "global warming" OR "greenhouse gas*") W/5 (mitigat* OR reduction OR reducing OR limit* OR limiting OR abatement OR protect* OR combat* OR tackl* OR stop* OR regulat* OR avoid*))) OR KEY(("soil" OR "land") AND (("climate change" OR "global warming" OR "greenhouse gas*") W/5 (mitigat* OR reduction OR reducing OR limit* OR limiting OR abatement OR protect* OR combat* OR tackl* OR stop* OR regulat* OR avoid*))))
Adapt to climate change	(TITLE(("soil" OR "land") AND (("climate change" OR "global warming") W/5 (adapt* OR resilien* OR adjust* OR support*))) OR KEY(("soil" OR "land") AND (("climate change" OR "global warming") W/5 (adapt* OR resilien* OR adjust* OR support*)))
Reduce soil degradation	(TITLE(("soil" OR "land") AND ("erosion" OR "compaction" OR "pollution" OR "degradation" OR "contamination" OR "desertification" OR "salinization" OR "acidification") W/5 ("zero net" OR reduce* OR reduction OR restorat* OR remediat* OR prevent* OR rehabilitat* OR stop* OR mitigat* OR limit* OR

	abatement OR protect* OR combat* OR tackl* OR regulat* OR avoid* OR improv* OR control* OR attenuat*)) OR KEY(("soil" OR "land") AND ("erosion" OR "compaction" OR "pollution" OR "degradation" OR "contamination" OR "desertification" OR "salinization" OR "acidification") W/5 ("zero net" OR reduce* OR reduction OR restorat* OR remediat* OR prevent* OR rehabilitat* OR stop* OR mitigat* OR limit* OR abatement OR protect* OR combat* OR tackl* OR regulat* OR avoid* OR improv* OR control* OR attenuat*)))
Improve ecosystem services	(TITLE(("soils" OR “land”) AND ("ecosystem* services" W/5 (increas* OR enhanc* OR reinforc* OR regulat* OR support* OR restaur*))) OR KEY(("soils" OR “land”) AND ("ecosystem* services" W/5 (increas* OR enhanc* OR reinforc* OR regulat* OR support* OR restaur*))))
Improve biodiversity	TITLE((“soil” OR “land”) AND ((“biodiversity” or “biota”) W/5 (increas* OR enhanc* OR reinforc* OR maintain* OR regulat* OR support* OR impact*))) OR KEY((“soil” OR “land”) AND ((“biodiversity” or “biota”) W/5 (increas* OR enhanc* OR reinforc* OR maintain* OR regulat* OR support* OR impact*)))
Improve disaster control	(TITLE(("soil" OR "land") AND (("wildfire" OR "forest fire" OR "landslide" OR "mudflow" OR "flood" OR "drought" OR "extreme weather" OR "extreme climate" OR "disaster" OR "dust storm") W/5 (mitigat* OR improv* OR prevent* OR control* OR reduc* OR stop* OR attenuat* OR avoid* OR protect* OR limit* OR resilien*))) OR KEY (("soil" OR "land") AND (("wildfire" OR "forest fire" OR "landslide" OR "mudflow" OR "flood" OR "drought" OR "extreme weather" OR "extreme climate" OR "disaster" OR "dust storm") W/5 (mitigat* OR improv* OR prevent* OR control* OR reduc* OR stop* OR attenuat* OR avoid* OR protect* OR limit* OR resilien*))))

Table 8: Detailed search request used per societal challenge

Living Labs and Lighthouses	(TITLE-ABS-KEY((“living labs” OR “lighthouses” OR “flaghship”)
Technical economic & social innovation	(TITLE((innovat* OR new) AND (technic* OR tech* OR economic* OR social* OR “practice” OR biol* OR manage* OR process* OR strategi*)) OR KEY((innovat* OR new) AND (technic* OR tech* OR economic* OR social* OR “practice” OR biol* OR manage* OR process* OR strategi*)))
Data management, sensing & monitoring	(TITLE(“data management” OR “sensing” OR monitor*) OR KEY(“data management” OR “sensing” OR monitor*))
Assessment & modelling	TITLE(model* OR assess* OR analy* OR “mapping” OR “maps”) OR KEY(model* OR assess* OR analy* OR “mapping” OR “maps”))
Awareness, training and education	(TITLE(“capacity building” OR “awareness” OR “training” OR “education”) OR KEY(“capacity building” OR “awareness” OR “training” OR “education”))
Science based policy support	(TITLE((“science” AND (policies OR policy)) OR “policy support” OR “policies support”) OR KEY((“science” AND (policies OR policy)) OR “policy support” OR “policies support”))
Institutions and governance	(TITLE(“governance” OR “institution”) OR KEY(“governance” OR “institution”))
Specific regions	(TITLE(“mountain” OR “peatland” OR “marshland” OR “coastal area” OR “artic” OR “karst area” OR “island” OR “mediterranean” OR “boreal”) OR KEY(“mountain” OR “peatland” OR “marshland” OR “coastal area” OR “artic” OR “karst area” OR “island” OR “mediterranean” OR “boreal”))
Specific sectors and practices	(TITLE(“vineyard” OR “orchard” OR “market gardening” OR “agroforestry” OR “mixed crop*” OR “intercrop*”) OR KEY(“vineyard” OR “orchard” OR “market gardening” OR “agroforestry” OR “mixed crop*” OR “intercrop*”))

Table 9: Detailed search request used per knowledge domain

Search strings for the cell: “awareness, training & education” X “increase biomass production”	**Explanations**
(TITLE(**("soil" OR "land")** AND (((increas* OR enhanc* OR reinforc* OR support*)) W/5 (food OR energy OR "crop" OR wood OR "yield" OR timber))) OR KEY(**("soil" OR "land")** AND (((increas* OR enhanc* OR reinforc* OR support*)) W/5 (food OR energy OR "crop" OR wood OR "yield" OR timber))))	Defined search terms to select articles in relation to soil or land and to the societal challenge “increase biomass production”
AND (TITLE(“capacity building” OR “awareness” OR “training” OR “education”) OR KEY(“capacity building” OR “awareness” OR “training” OR “education”))	Defined search terms to select articles in relation to the knowledge domain “awareness, training & education”
AND (LIMIT-TO(DOCTYPE,"ar"))	Select only journal articles
AND (EXCLUDE(PUBYEAR, 2021))	Not to select articles published in 2021

Table 10: Example of a search string used in Scopus for a given cell

ANNEX III: METHODOLOGY – Textual analysis description

The textual analysis consists of two main steps (EL Akkari et al., 2018).

- The first step aims to identify the most used words or groups of words (terms) within the articles (title, abstract and keywords) and to calculate their frequency in the overall corpus. Words without specific meaning (conjunctions, words present in all scientific articles) are eliminated. Synonyms (words or terms) are combined, and then the list of the main terms found (which have been combined or not) in the corpus is generated.
- The second step of the textual analysis aims to calculate the frequency with which two terms occur in the same article. Maps, called network mapping, are then created to present the results in a synthetic form. These maps provide a visual representation of the topics covered in the corpus. These "visualisations" allow us to assess which terms appear most frequently, and which appear most frequently together, by organising them into groups of related main terms, called clusters. By analysing the terms and the relationships between terms within a cluster, it is possible to identify a specific theme within that group of articles. The relationships between clusters can highlight how different themes in the corpus are related to each other.

For this study, we used the text analysis program CorTexT Manager. This digital text analysis platform was developed by IFRIS (Institute For Research and Innovation in Society). IFRIS is a consortium of research units in France working on issues related to interactions between science, technology and society as well as research and innovation policies. CorTexT Manager allows for large-scale literature reviews and correlation of large volumes of data (Aviso et al., 2020; Ubando et al., 2021).

Per cell of the SMS Knowledge Matrix, a content analysis of the corpus was conducted (Figure 9). The analyses focus on three key points: (i) the interest on the topic over time; (ii) a general overview of the existing R&I knowledge and (iii) the key knowledge hubs, that is to say the main actors publishing on the topic.

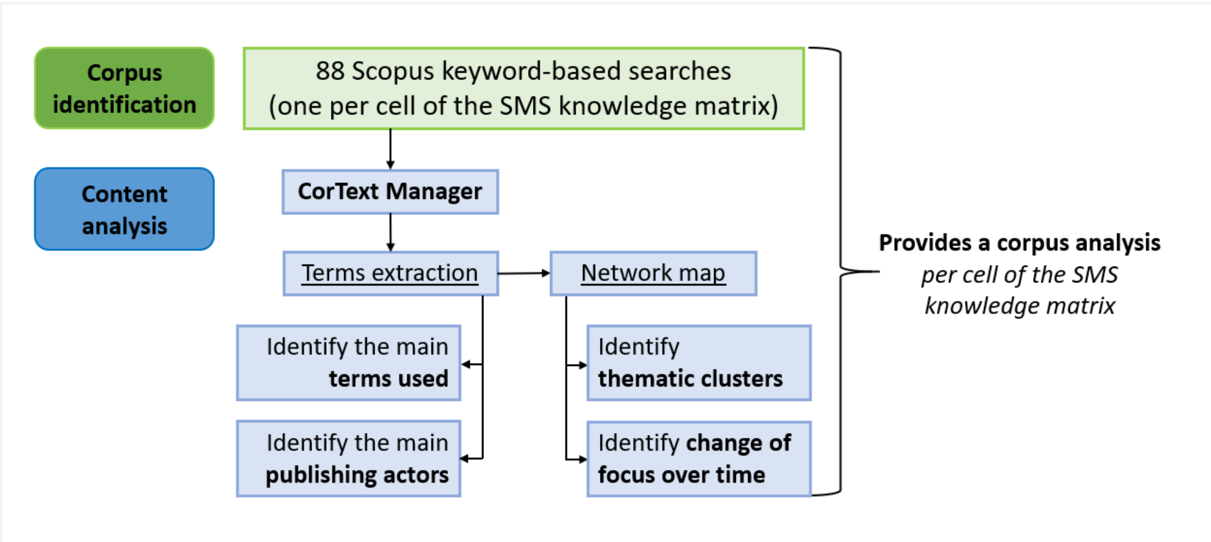


Figure 9: Diagram of the procedure followed to provide an analysis of the corpus

Limitation of our literature review

The bibliographic search method used in this study has its limitations. Only documents written in English were collected. Furthermore, although our search strategy is robust for peer-reviewed journal articles, we may have missed some relevant articles in other formats (e.g. conference papers, books, chapters). Non-academic studies are not present in this inventory of articles. Documents not published in peer-reviewed journals, such as those intended to support public policy, have certainly been omitted. That being said, articles are the most important documentation for conducting literature reviews.

CorTexT has also a number of limitations. The network maps vary depending on whether the number of articles in a corpus is large or small, which has a partial impact on the robustness of the results. Furthermore, the network maps from CorTexT only document the frequency with which two terms occur in the same article, without attributing the meaning of a cluster to a topic. The choice of a given cluster name is made "by hand" by an expert based on his knowledge. The role of experts in the naming phase of a cluster introduces a subjective element that needs to be recognised.

ANNEX IV: METHODOLOGY – Overview of the European R&I landscape

An **institute** is defined in deliverable 2.3 as any research, science or technological organization, institute, university, whether in the public or private sector, whether large or small which conducts research, science, or technology related to the Mission Objectives as a part of its activities in a particular country. A **Network** is defined as a group of three or more interdependent R&I actors and has relationships between them with a common interest in relation to Mission Objectives, existing at the national, European, or International level (for e.g. at the national level (The Danish Society for Nature Conservation), Climate Action Network Europe (CAN Europe), FAO (global)).

A different method was used to identify each of the following R&I actors, that is to say (i) institutions & networks, (ii) H2020 projects, (iii) JPI URBAN, JPI FACCE, JPI CLIMATE, and (iv) Living Labs:

(i) The European soil and land-related R&I institutions and networks (EU and associated countries) are identified via open-source online platforms like Google search for institutions from each country, LinkedIn, and Partners (Institutions and networks) of Global Soil Partnership. The preliminary list of 300 extracted institutions and networks was circulated to the SMS members for validation of the institutions in order to identify the most relevant actors. An online survey form was sent by email to each institution to assess whether and to what extent they address the Mission Objectives. For institutions that did not reply to the survey, SMS evaluated the institutions information through their respective website (desk study).

(ii) Ongoing or recently finished H2020 projects (max. six months before the assessment, i.e. March 2021) were identified from the EU CORDIS platform using the keyword 'soil'. CORDIS is the European Commission's primary public repository and portal to disseminate information on all EU-funded research projects and their results in the broadest sense. Project titles and descriptions were screened for relevance regarding sustainable soil and land management and 87 respective projects were selected for further assessment. Project representatives were contacted via email and asked to fill in an online survey to find out to what extent the projects address the eight Mission Objectives. In total, 13 projects replied to the survey. For all projects that did not reply to the survey, SMS evaluated the project information on the CORDIS portal. Where applicable, information from the project web page was included to fill in a simplified version of the survey.

(iii) In addition to the H2020 projects, projects belonging to the family of Joint Project Initiatives related to agriculture (JPI FACCE), urban land-use (JPI URBAN), climate action (JPI CLIMATE) were identified from their respective websites using the keyword 'soil'.

(iv) Potential Living Labs (LLs) were collected in close exchange with DG AGRI and complemented through an extensive online desk study. The list of potential LLs was circulated among the SMS project members to identify missing LLs. We want to emphasize here that although these LLs were chosen according to the criteria as identified in SMS D3.1 'Concept note on criteria for setting up Living Labs and Lighthouses', the LL list is not yet finalized, and requires further validation. Hence, changes regarding LLs may occur in upcoming deliverables.

ANNEX V: METHODOLOGY – Actors needs assessment

The purpose of the actor needs assessment is a prioritization of the “needs” or “interests” of actors to be engaged in sustainable soil and land management. Knowing these needs helps to engage actors in the SMS activities, such as setting up the roadmap for sustainable land and soil management linked to the objectives of the HE Mission “A soil deal for Europe”, and the HE Mission's activities, such as engagement in the Soil Health Living Labs.

Primary source of information for achieving insight in the actor needs was the SMS survey on actor needs. Furthermore, two workshops were held with actors. However, as these workshops only engaged a relative low number of actors compared to the survey, the results of the workshops are only used as supplementary source of information. The survey focused on actors needs and priorities related to achievement of the objectives of the HE Mission. The survey contained both multiple choice and open-ended questions and was sent out to the long list of actors as identified in D3.2 detailed actor analysis (László et al., 2022). This list included many European networks covering different land uses and actor categories, the SMS Advisory Board, people and networks that signed a LoS to the SMS proposal, the representative dedicated expert group that supports the setup of the roadmap (See D3.4). The workshops were 1) a special session at the AquaConSoil conference, where mainly R&I and advisors were represented, on the topic of industrial soils and 2) the earlier mentioned, dedicated actor group for road mapping activities. This is a very representative group, covering all land uses and different actor categories and, because of the networks that are represented in this group, also the different MS.

For each of the eight Mission Objectives, the survey respondents were asked to indicate how important (of great significance or value) and how urgent they consider the specific objective for their organisation. Respondents had the option to tick one of the next boxes: very, fairly, neutral, slightly, not at all, not applicable or no opinion. Thereafter they were asked to briefly motivate their answer by ticking one of the indicated options in the survey and/or fill out some text.

In the survey as well as in the workshops, the actors were asked to specify their needs regarding the Mission Objectives. These results were clustered per Mission Objective and – where feasible – under each objective also clustered per actor group. The most important actor needs were identified through a joint analysis and synthesis of the outcome of the survey as well as the workshops. A word cloud instrument was used to support this analysis and synthesis by showing the most common terms in the responses. Results were summarized for each of the Mission Objectives in D3.4 (for a summary, see also chapter 4.2).

Likewise, the methodology used to identify gaps also has its own limitations. As the actors R&I needs were identified per mission objective and the stocktake per societal challenge, some knowledge may have been overlooked when translating the knowledge stock from the societal challenges into the mission objectives.

ANNEX VI: RESULTS – Respondents description of the survey on R&I needs

In total 93 respondents filled out the survey: 32 partly and 61 fully. The distribution of the respondents over the different actor groups, countries where they are active and land uses are displayed in the figures underneath (Figure 10, Figure 11 and Figure 12).

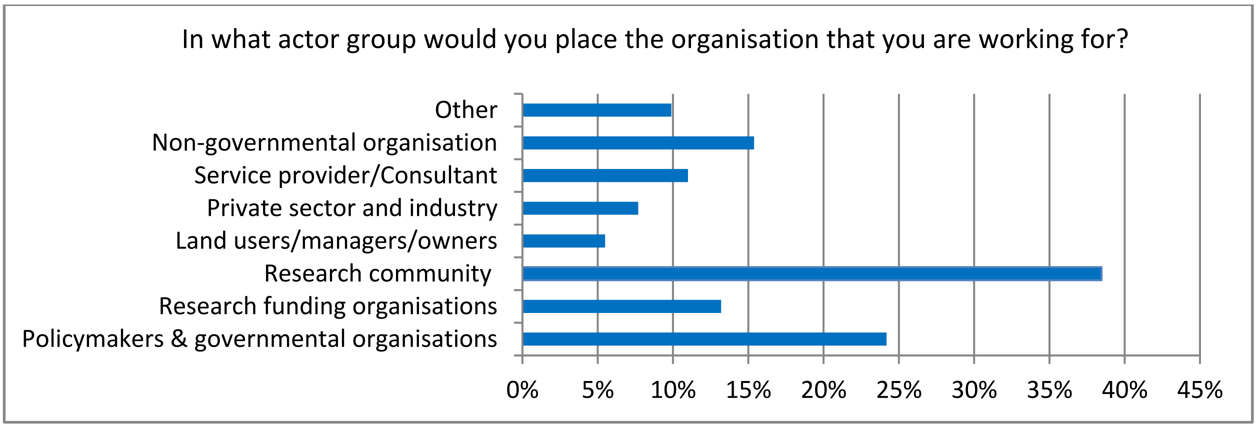


Figure 10: Question related to the respondent's actor group [multiple answers possible] (n = 91)

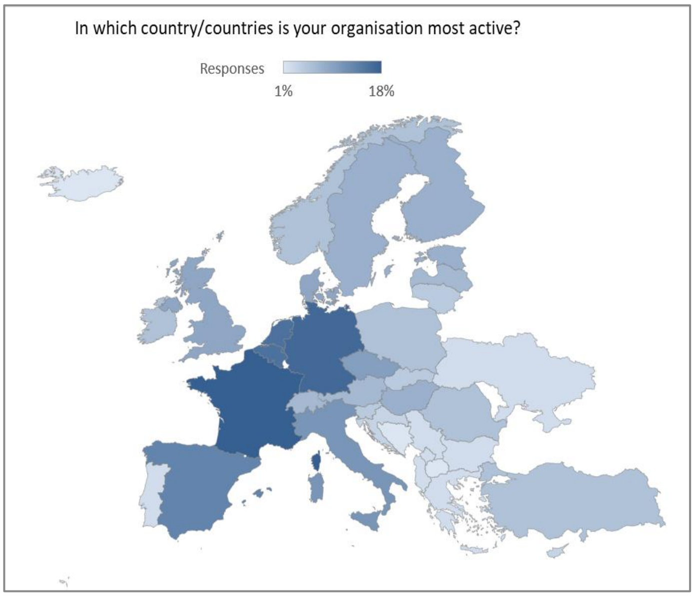


Figure 11: Map representation of countries in which actor's organisation are most active (n=90)

The response "European Union" is not represented on the map (16% of the responses).

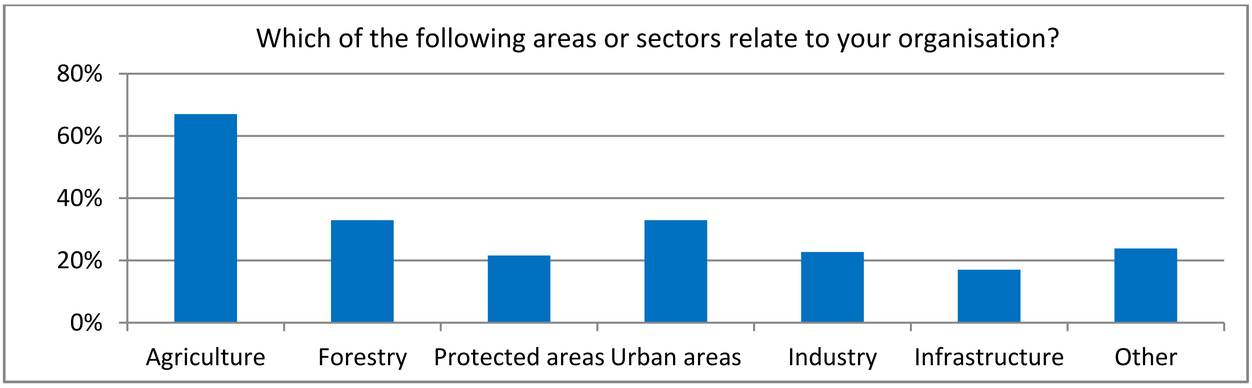


Figure 12: Question related to the respondent's sector [multiple answers possible] (n=88)

ANNEX VII: RESULTS – Actor needs priority

When looking at the needs of the actors in relation to the different Soil Mission objectives, it appears that there are many similarities in general, but also that the needs are concentrated when it comes to the specific objectives. After a joint analysis and synthesis of the outcome of the survey as well as the workshops it is concluded that the generic actor needs – i.e. applicable to all the actor groups – in order of priority are:

1. **Funding**:
This appears the number one need for all the actor groups, but they need it for different reasons, which are linked to their specific actor interests, e.g.:
- Policy and governmental organisations need it for capacity,
- The research community needs it for R&I including (long-term) observation,
- Landowners and private sector need it for the implementation of measures/infrastructure.

2. **Legislation/policy frameworks**:
This appears the number two need for all the actor groups, but legislation/policy needs vary between the various actor groups, e.g.:
- Policy and governmental organisations need it to set clear boundaries and targets,
- Landowners and private sector need it to create a level playing field, receive guidance and act.

3. **Knowledge/R&I in order to inform policy and measures**:
For some of the Soil Mission objectives there is a clear need expressed for knowledge/R&I to inform policy making (legislation/frameworks) as well as to inform the design or increase the effectiveness of measures (e.g. solutions, best practices to improve land management, restore carbon stocks etc.)

4. **Awareness raising and communication**:
Different actor groups express different viewpoints regarding awareness raising and communication. In general, the involvement of citizens is regarded as very important for any actor interacting with society. Furthermore, reaching out to, for example farmers and project developers, is also regarded as an important need.

ANNEX VIII: RESULTS – Factsheets on the results of our literature review per societal challenge

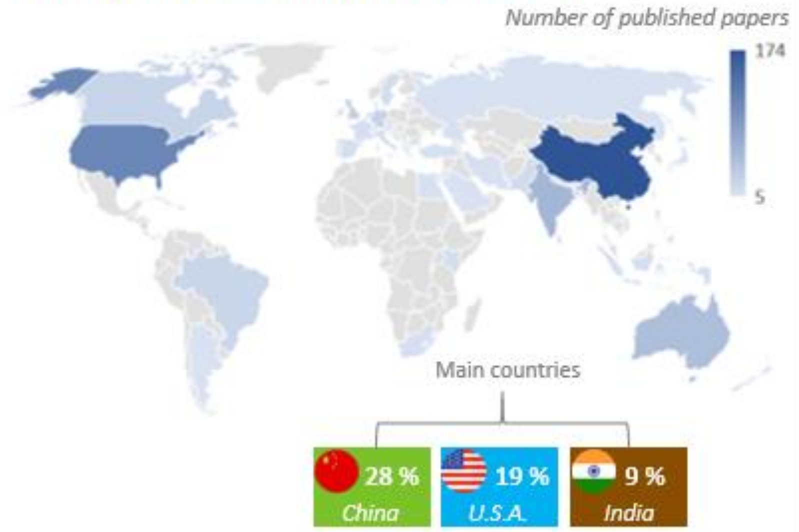
1. Societal challenge: improve biomass production

Soil Mission Support

Literature review: knowledge stock per societal challenge

Increase biomass production

Worldwide concentration of publications



Highlights

Between 1974 and 2020, **613 peer-reviewed articles** relating to increase biomass production and soil or land came out. About half of these articles were published in the last five years (i.e., 2016 - 2020).

Worldwide, more than **37 institutions** published at least 5 articles mainly from China, United States, India, Australia and United Kingdom.

Main institutions in Europe

Chronology of publications

Literature review: knowledge stock per societal challenge

Increase biomass production

Cluster map of the main terms used

Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are "organic matter", "soil water", "bulk density", "water use efficiency" and "crop growth".

Some **knowledge types are very little discussed** in articles. "Awareness, training & education", "science-based policy support", "institution & governance", "technical, social & economic innovation" and "living labs & lighthouses" are scoring the lowest.

Knowledge types

- **1 %** Data management, sensing & monitoring
- **0 %** Science-based policy support
- **3 %** Specific sectors and practices
- **0 %** Living labs & lighthouses
- **20 %** Assessment & modelling
- **0 %** Institution & governance
- **76 %** Basic knowledge production
- **0,5 %** Technical, economic & social innovation
- **0 %** Awareness, training & education
- **1 %** Specific regions

→ **In total 613 articles**

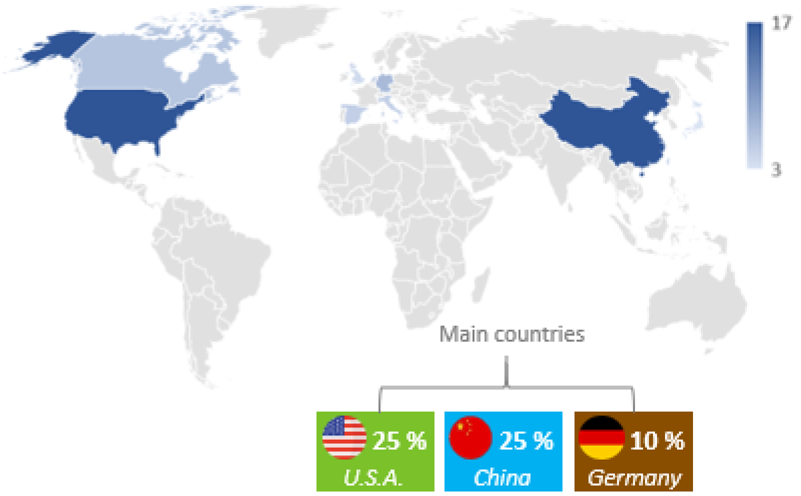
2. Societal challenge: mitigate land take

Soil Mission Support

Literature review: knowledge stock per societal challenge

Mitigate land take

Worldwide concentration of publications

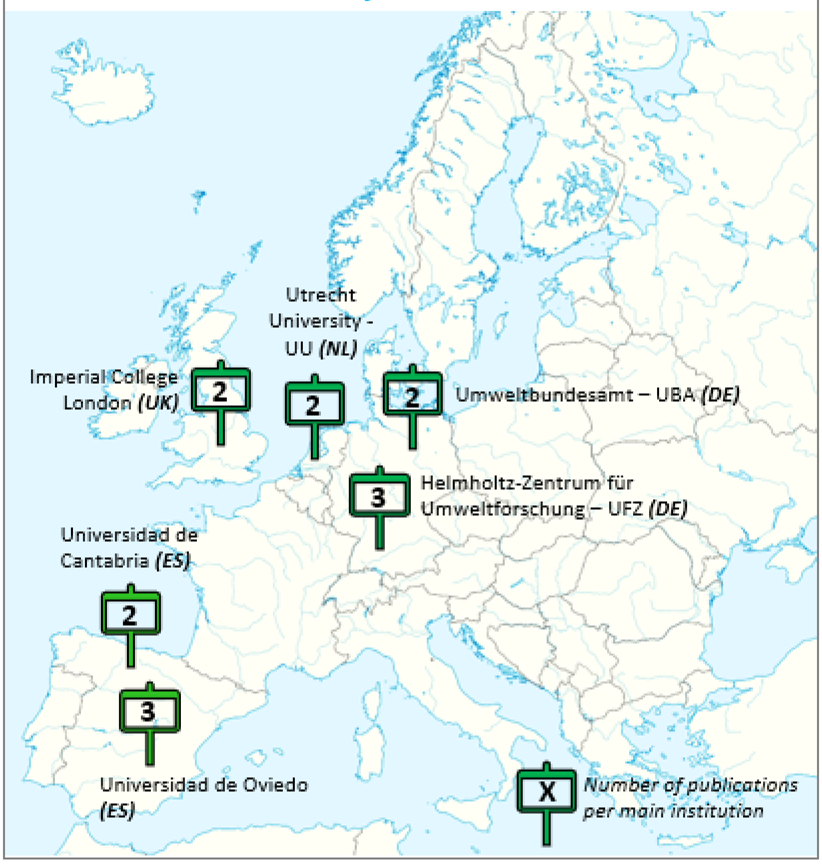


Highlights

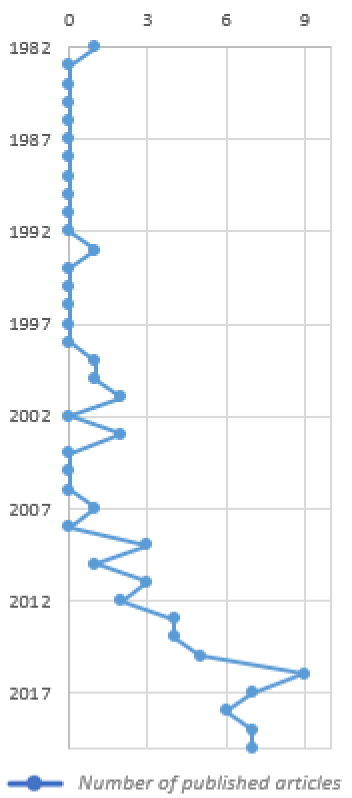
Between 1982 and 2020, **67 peer-reviewed articles** relating to land take mitigation and soil or land came out. 54 % of the articles were published in the last five years (i.e., 2016 - 2020).

Worldwide, more than **15 institutions** published at least 2 articles, mainly from the United States, China, Germany, and Canada.

Main institutions in Europe



Chronology of publications

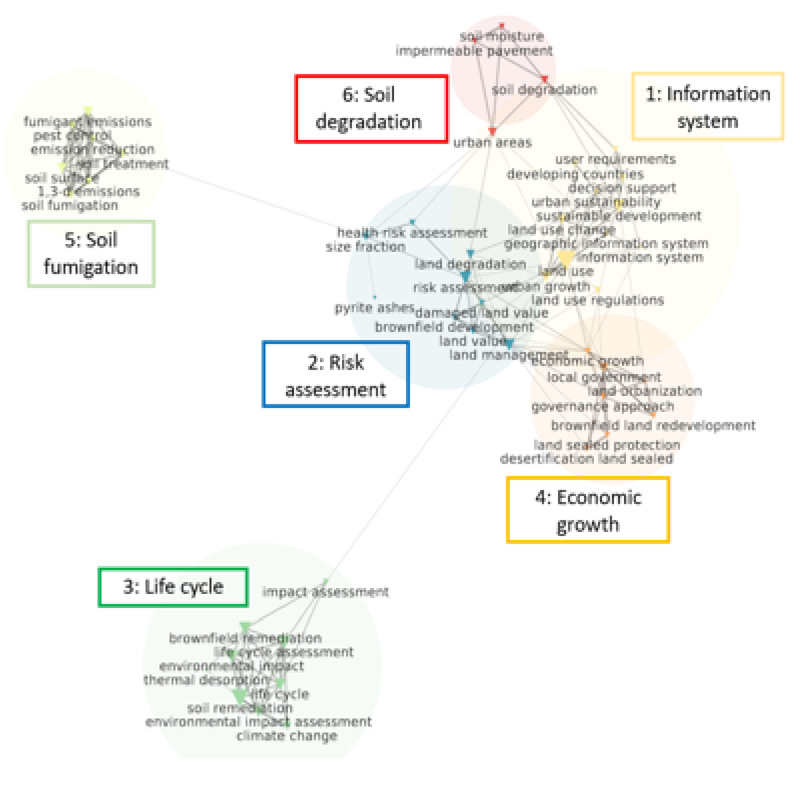


Soil Mission Support

Literature review: knowledge stock per societal challenge

Mitigate land take

Cluster map of the main terms used



Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are "land use", "brownfield remediation", "soil remediation", "risk assessment" and "life cycle".

Some **knowledge types are very little discussed** in articles. "Awareness, training & education", "institution & governance", "specific sectors and practices" and "living labs & lighthouses" are scoring the lowest.

Knowledge types

Data management, sensing & monitoring	12 %
Science-based policy support	34 %
Specific sectors and practices	1 %
Living labs & lighthouses	0 %
Assessment & modelling	22 %
Institution & governance	0 %
Basic knowledge production	22 %
Technical, economic & social innovation	16 %
Awareness, training & education	0 %
Specific regions	4 %

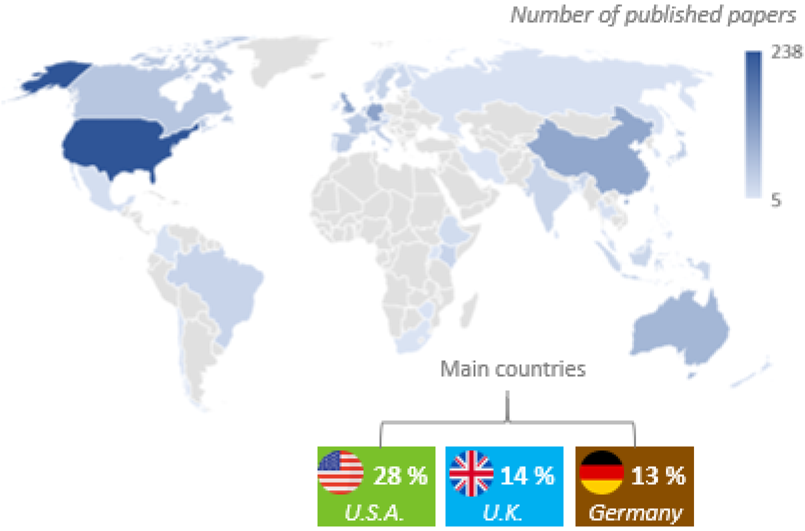
→ **In total 67 articles**

3. Societal challenge: mitigate climate change

Literature review: knowledge stock per societal challenge

Mitigate climate change

Worldwide concentration of publications

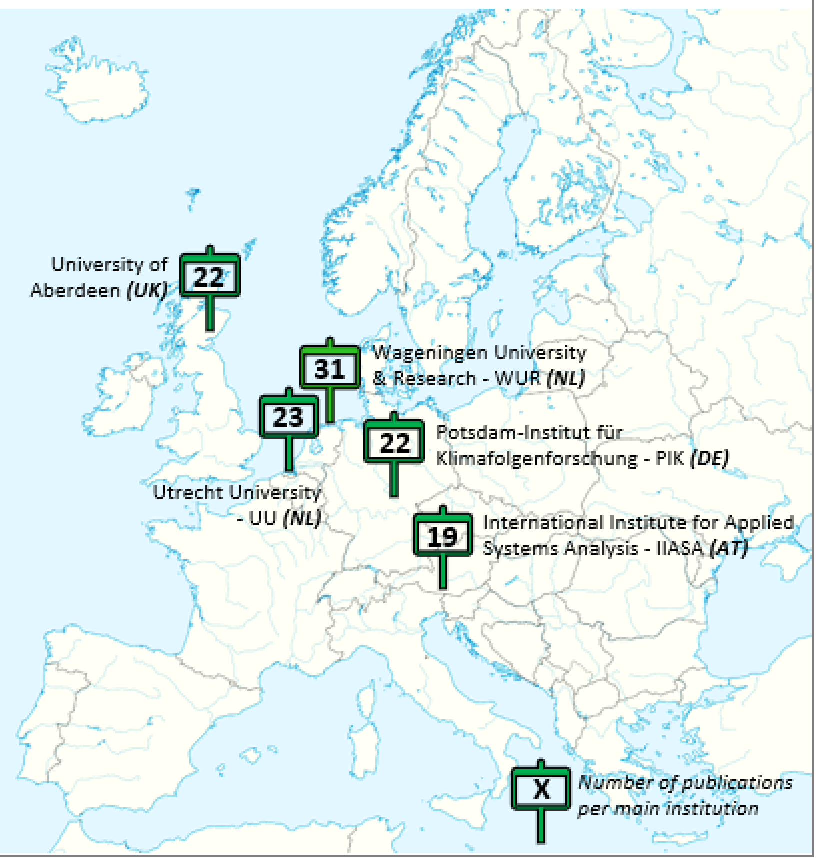


Highlights

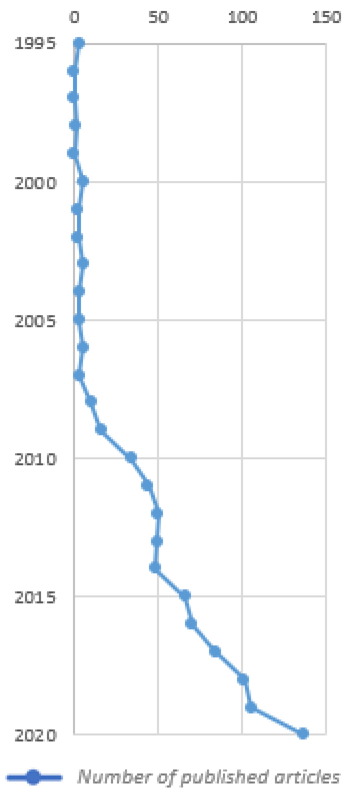
Between 1995 and 2020, **837 peer-reviewed articles** relating to climate change mitigation and soil or land came out. 60% of the articles were published in the last five years (i.e., 2016 - 2020).

Worldwide, more than **110 institutions** published at least 5 articles, mainly from the United States, United Kingdom, Germany and China.

Main institutions in Europe



Chronology of publications

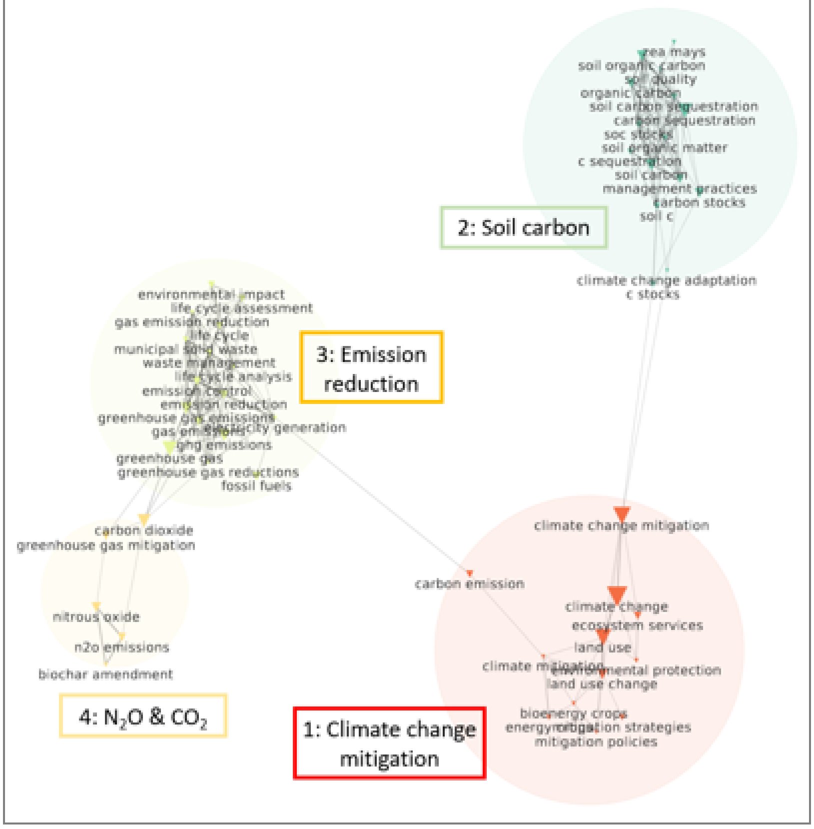


Soil Mission Support

Literature review: knowledge stock per societal challenge

Mitigate climate change

Cluster map of the main terms used



Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are "greenhouse gas emissions", "N_2O & CO_2", "land use change", "soil organic matter" and "life cycle".

Some **knowledge types are very little discussed** in articles. "Awareness, training & education", "science-based policy support", "institution & governance", "innovation" and "living labs & lighthouses" are scoring the lowest.

Knowledge types

- **8 %** Data management, sensing & monitoring
- **0 %** Science-based policy support
- **4 %** Specific sectors and practices
- **0 %** Living labs & lighthouses
- **56 %** Assessment & modelling
- **1 %** Institution & governance
- **37 %** Basic knowledge production
- **1 %** Technical, economic & social innovation
- **0,5 %** Awareness, training & education
- **6 %** Specific regions

→ In total 837 articles

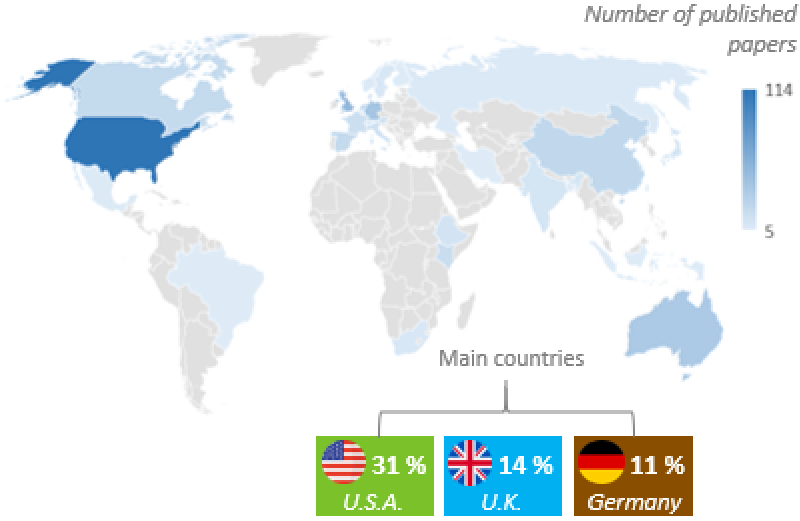
4. Societal challenge: adapt to climate change

Soil Mission Support

Literature review: knowledge stock per societal challenge

Adapt to climate change

Worldwide concentration of publications

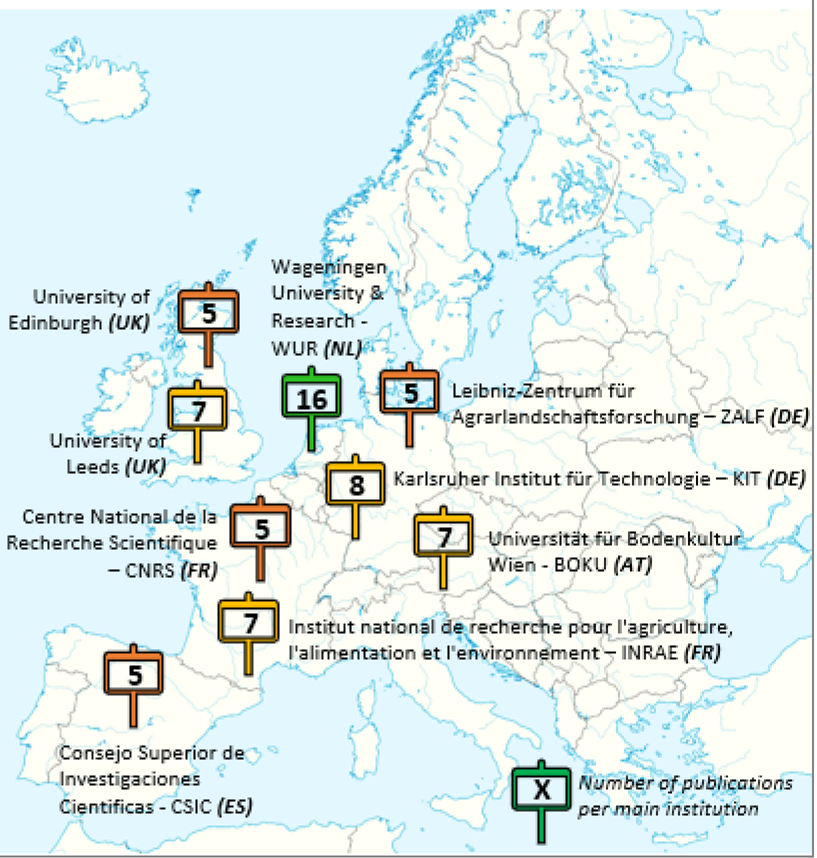


Highlights

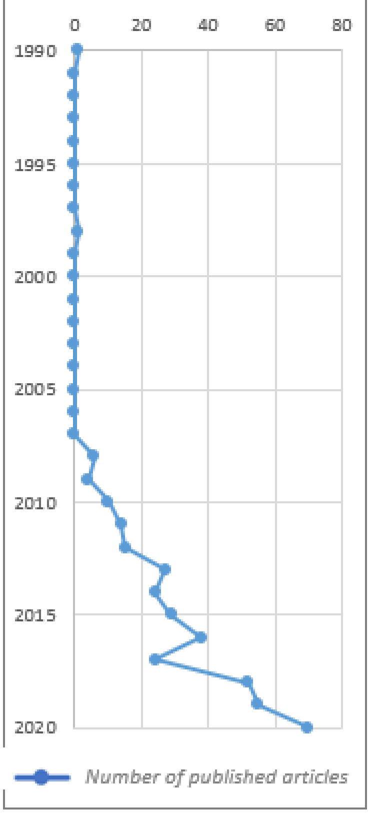
Between 1990 and 2020, **370 peer-reviewed articles** relating to climate change adaptation and soil or land came out. 64% of the articles were published in the last five years (i.e., 2016 - 2020).

In Europe, **9 institutions** published at least 5 articles, mainly from the Netherlands, United Kingdom, Germany, France, Austria and Spain.

Main institutions in Europe



Chronology of publications

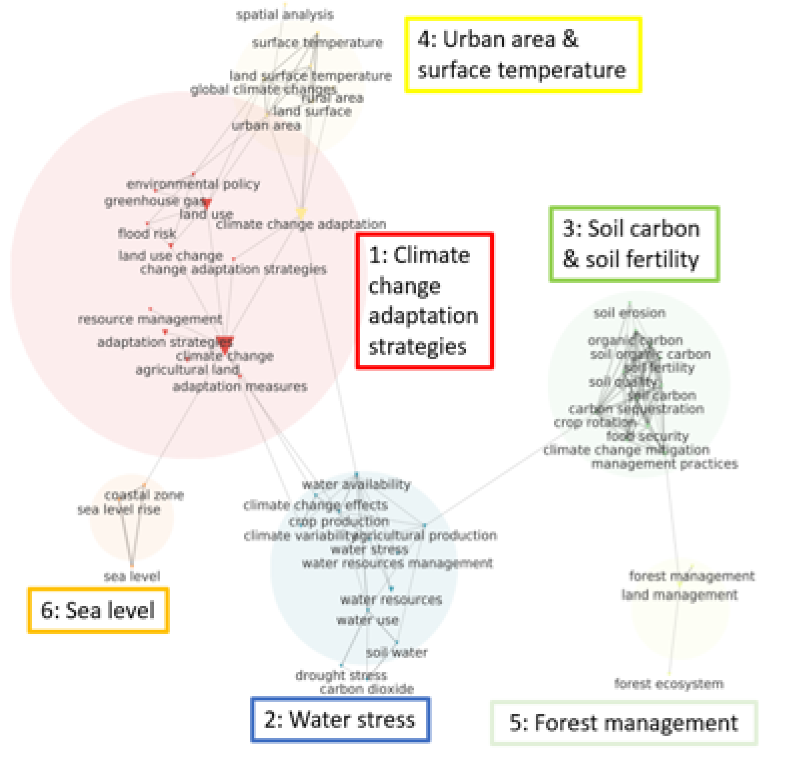


Soil Mission Support

Literature review: knowledge stock per societal challenge

Adapt to climate change

Cluster map of the main terms used



Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are "land use", "adaptation measures", "management practices", "water resource" and "food security".

Some **knowledge types are very little discussed** in articles. "Awareness, training & education", "science-based policy support", "technical, economic & social innovation" and "living labs & lighthouses" are scoring the lowest.

Knowledge types

- 4 % — Data management, sensing & monitoring
- 1 % — Science-based policy support
- 4 % — Specific sectors and practices
- 0 % — Living labs & lighthouses
- 59 % — Assessment & modelling
- 4 % — Institution & governance
- 27 % — Basic knowledge production
- 0 % — Technical, economic & social innovation
- 1 % — Awareness, training & education
- 9 % — Specific regions

→ **In total 370 articles**

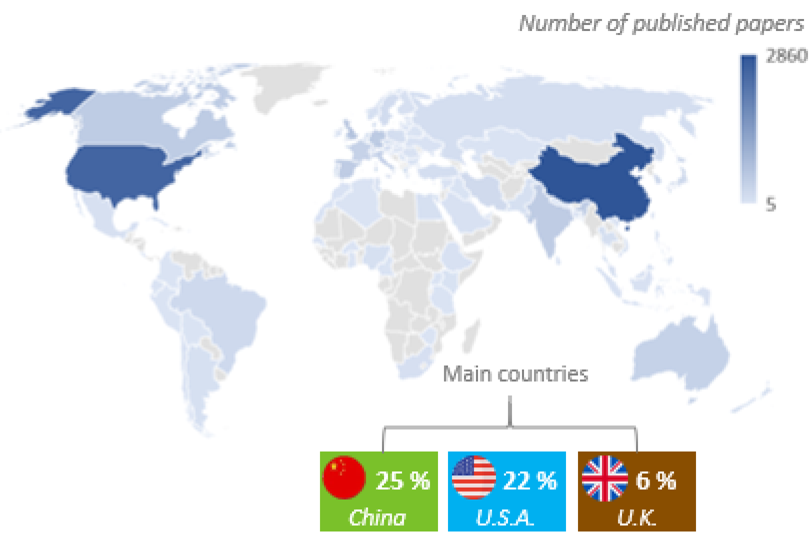
5. Societal challenge: reduce soil degradation

Soil Mission Support

Literature review: knowledge stock per societal challenge

Reduce soil degradation

Worldwide concentration of publications



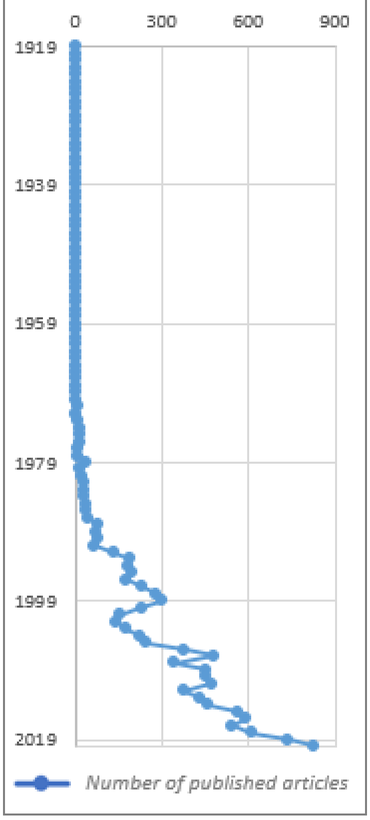
Highlights

Between 1919 and 2020, **11 285 peer-reviewed articles** relating to soil degradation reduction and soil or land came out. 30% of the articles were published in the last five years (i.e., 2016 - 2020).

Worldwide, more than **140 institutions** published at least 20 articles, mainly from China, United States, United Kingdom and Germany.

Main institutions in Europe

Chronology of publications

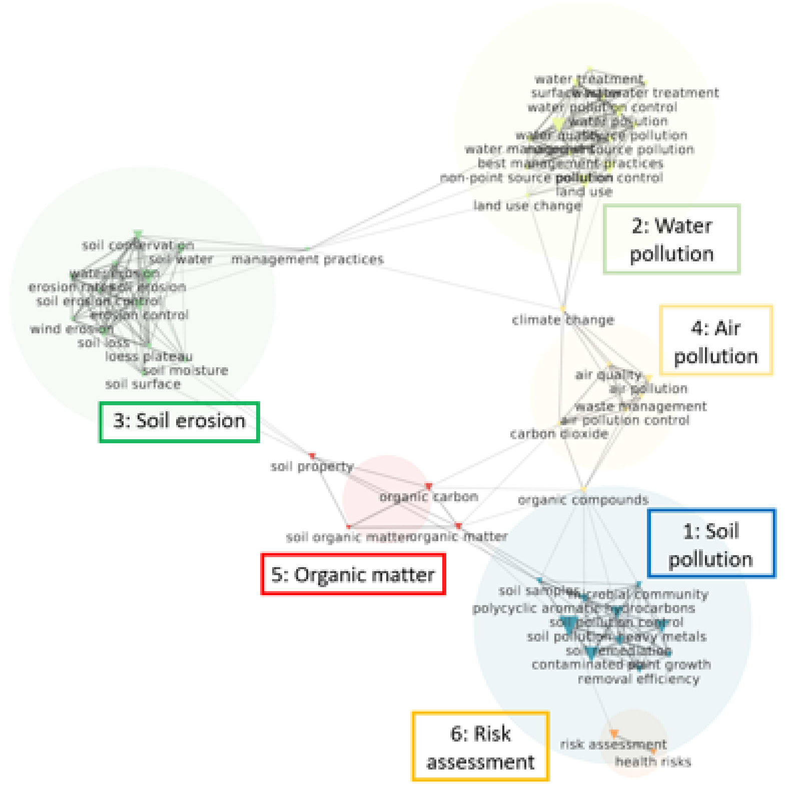


Soil Mission Support

Literature review: knowledge stock per societal challenge

Reduce soil degradation

Cluster map of the main terms used



Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are "soil pollution control", "soil erosion", "land use", "contaminated soil", "heavy metals" and "water quality".

Some **knowledge types are very little discussed** in articles. "Awareness, training & education", "science-based policy support", "institution & governance", "technical, economic & social innovation" and "living labs & lighthouses" are scoring the lowest.

Knowledge types

- **14 %** Data management, sensing & monitoring
- **0,1 %** Science-based policy support
- **2 %** Specific sectors and practices
- **0,1 %** Living labs & lighthouses
- **45 %** Assessment & modelling
- **0,5 %** Institution & governance
- **48 %** Basic knowledge production
- **1 %** Technical, economic & social innovation
- **1 %** Awareness, training & education
- **4 %** Specific regions

→ **In total 11 285 articles**

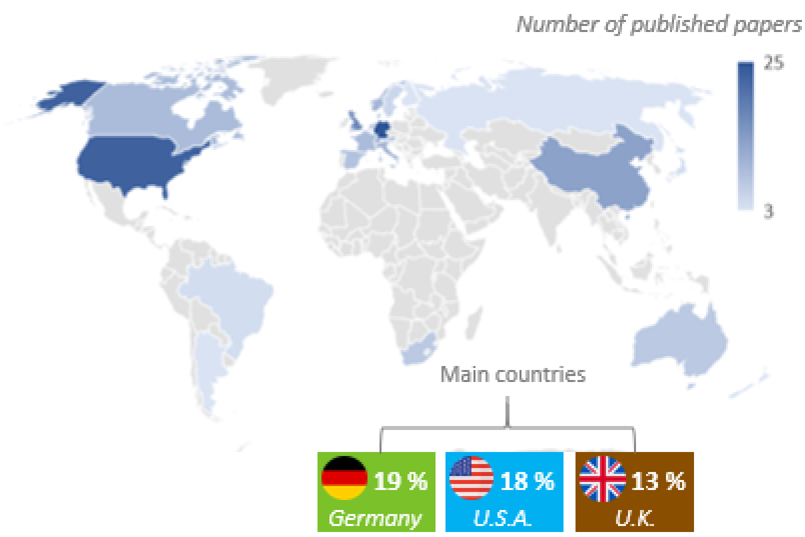
6. Societal challenge: increase biodiversity

Soil Mission Support

Literature review: knowledge stock per societal challenge

Increase biodiversity

Worldwide concentration of publications



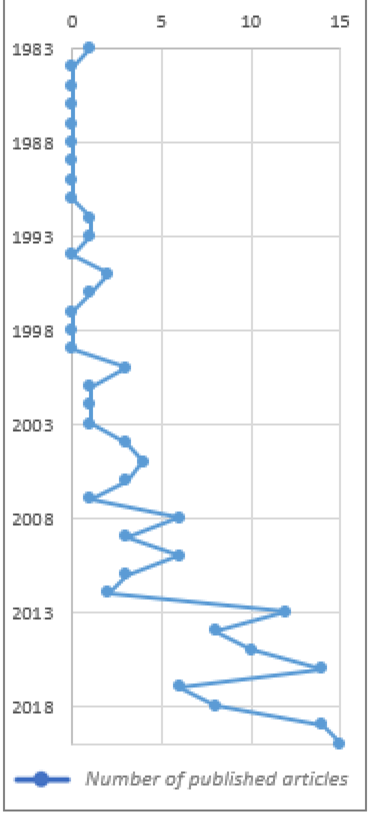
Highlights

Between 1983 and 2020, **130 peer-reviewed articles** relating to biodiversity increase and soil or land came out. 44 % of the articles were published in the last five years (i.e., 2016 - 2020).

Worldwide, more than **15 institutions** published at least 3 articles, mainly from Germany, United States, United Kingdom and Switzerland.

Main institutions in Europe

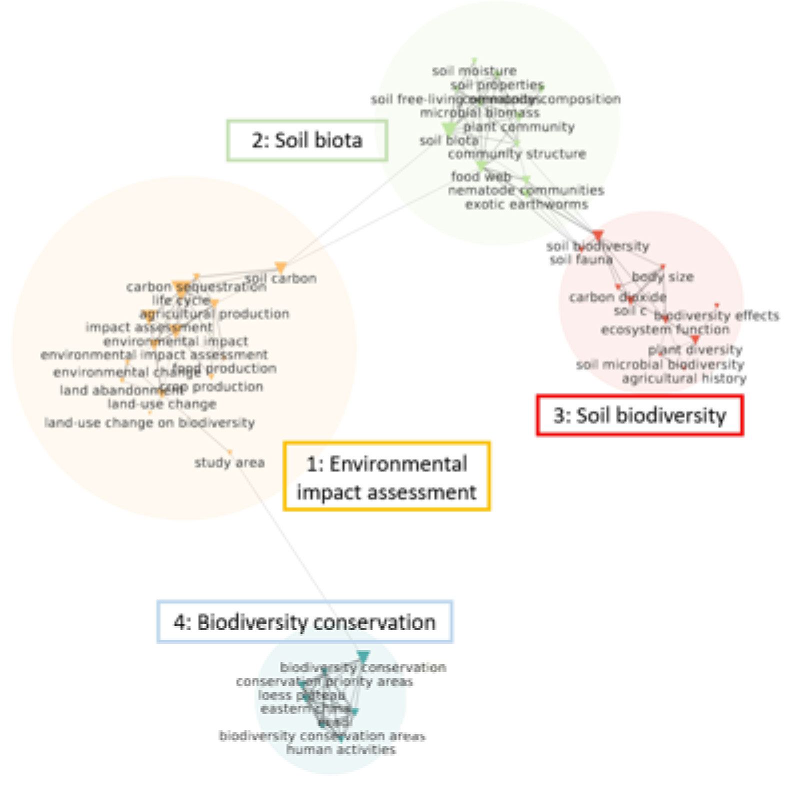
Chronology of publications



Literature review: knowledge stock per societal challenge

Increase biodiversity

Cluster map of the main terms used



Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are "life cycle", "impact assessment", "biodiversity conservation", "soil biota" and "land use change".

Some **knowledge types are very little discussed** in articles. "Awareness, training & education", "science-based policy support", "institution & governance", "technical, economic & social innovation" and "living labs & lighthouses" are scoring the lowest.

Knowledge types

	3 % Data management, sensing & monitoring	0 % Science-based policy support	2 % Specific sectors and practices
0 % Living labs & lighthouses	55 % Assessment & modelling	0 % Institution & governance	40 % Basic knowledge production
0 % Technical, economic & social innovation	1 % Awareness, training & education	7 % Specific regions	→ In total 130 articles

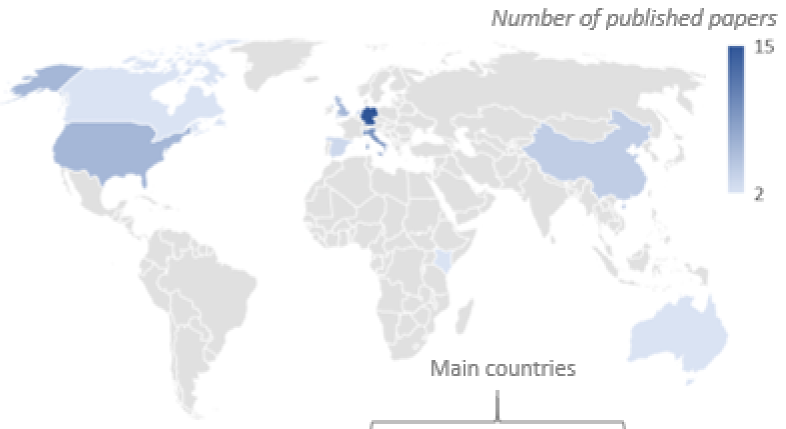
7. Societal challenge: increase ecosystem services

Soil Mission Support

Literature review : knowledge stock

Increase provision of ecosystem services

Worldwide concentration of publications



35 % Germany | 21 % Italy | 14 % U.K.

Highlights

Between 2010 and 2020, **45 peer-reviewed articles** relating to the provision increase of ecosystem services and soil or land came out. 66 % of the articles were published between 2016 and 2020.

Worldwide, more than **10 institutions** published at least 2 articles, mainly from Germany, Italy , United Kingdom and United States.

Main institutions in Europe

- 4 *Articles published* – Leibniz Universität Hannover ***(DE)***
- 4 *Articles published* – Leibniz-Zentrum für Agrarlandschaftsforschung - ZALF ***(DE)***
- 3 *Articles published* – Christian-Albrechts-Universität zu Kiel ***(DE)***

Knowledge types

- 0 % Data management, sensing & monitoring
- 11 % Science-based policy support
- 4 % Specific sectors and practices
- 2 % Living labs & lighthouses
- 49 % Assessment & modelling
- 0 % Institution & governance
- 9 % Basic knowledge production
- 11 % Technical, economic & social innovation
- 0 % Awareness, training & education
- 13 % Specific regions

→ In total 45 articles

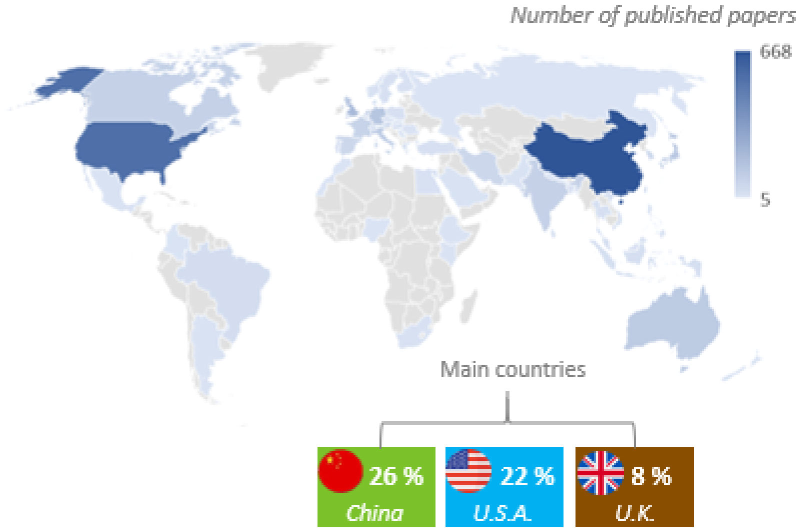
8. Societal challenge: improve disaster control

Soil Mission Support

Literature review: knowledge stock per societal challenge

Improve disaster control

Worldwide concentration of publications



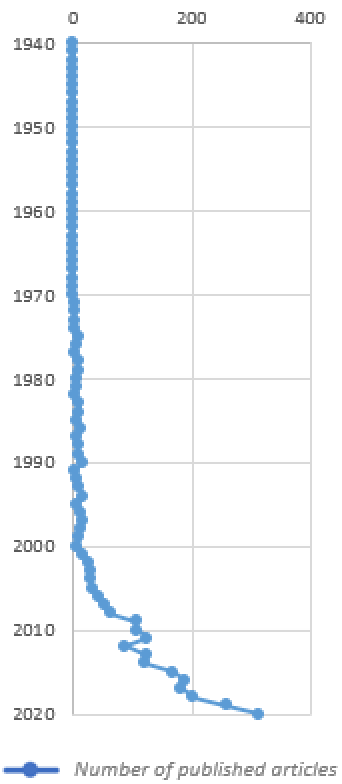
Highlights

Between 1940 and 2020, **2 527 peer-reviewed articles** relating to improve disaster control and soil or land came out. About half of these articles were published in the last five years (i.e., 2016 - 2020).

Worldwide, more than **130 institutions** published at least 6 articles mainly from China, United States, United Kingdom, Germany and Japan.

Main institutions in Europe

Chronology of publications

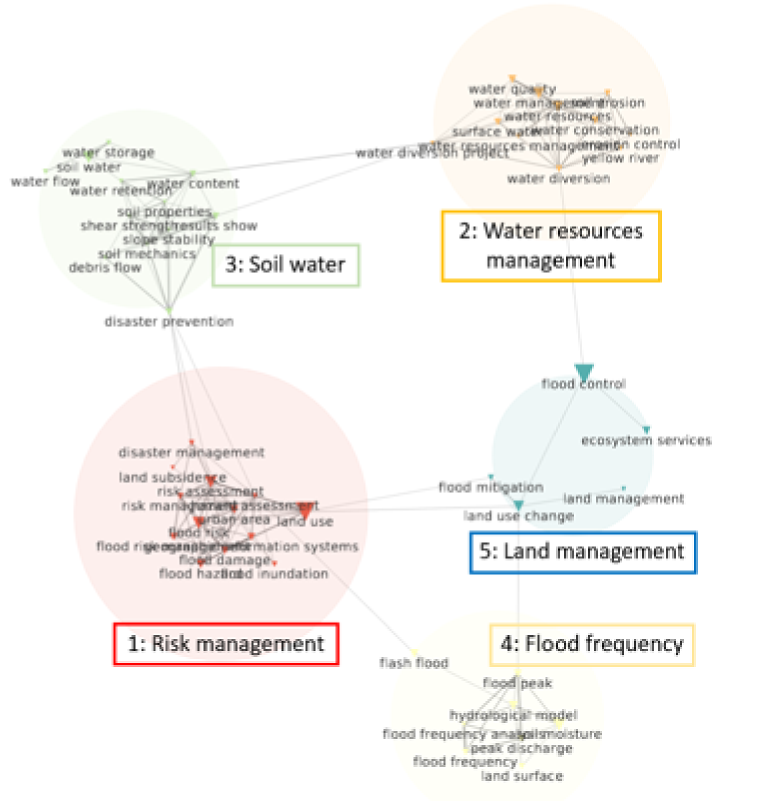


Soil Mission Support

Literature review: knowledge stock per societal challenge

Improve disaster control

Cluster map of the main terms used



Highlights

A textual analysis highlights that the **most frequently used terms** in titles, abstracts and keywords within all articles in descending order are “land use”, “flood risk”, “flood control”, “soil moisture”, “water resource” and “risk management”.

Some **knowledge types are very little discussed** in articles. “Science-based policy support”, “Specific sectors & practices”, and “Living labs & lighthouses” are scoring the lowest.

Knowledge types

Knowledge type	Share
Data management, sensing & monitoring	12 %
Science-based policy support	0,1 %
Specific sectors and practices	0,5 %
Living labs & lighthouses	0,1 %
Assessment & modelling	64 %
Institution & governance	1 %
Basic knowledge production	29 %
Technical, economic & social innovation	1 %
Awareness, training & education	1 %
Specific regions	6 %

→ In total 2 527 articles

ANNEX IX: RESULTS – Detailed literature review per societal challenge

1. Societal challenge: increase biomass production

Knowledge domain: entire societal challenge

- **Interest in the topic**

613 scientific journal articles related to biomass production increase were identified. The articles were published between 1974 and 2020. There has been a significant increase in general attention in this area since 2009 (Figure 13). The number of articles being published increased each year and reaches 95 in 2020. More than half of the existing articles on the topic (317/613, 52 %) were published in the last five years between 2016 and 2020.

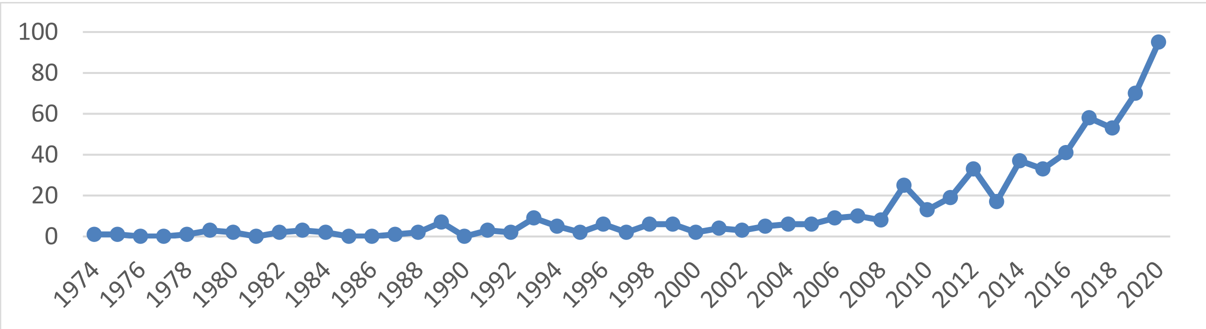


Figure 13: Chronologic number of articles published on "increase biomass production"

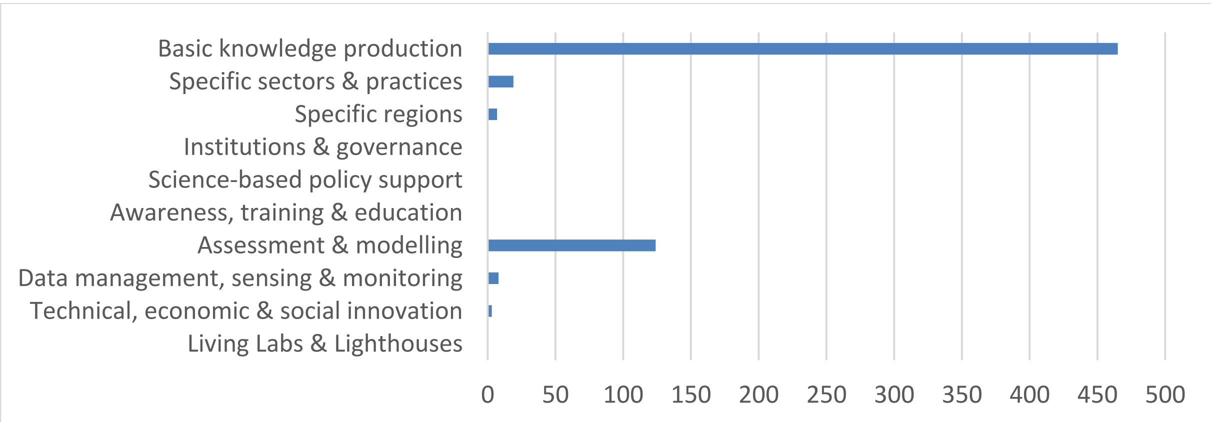


Figure 14: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 613 articles (Figure 14). One article can address several knowledge domains. At least 465 articles are on basic knowledge production, not related to any particular knowledge domain (465/613, 76 %). 20 % of all articles (124/613) have a focus on the knowledge domain "assessment and modelling". The other knowledge domain which is addressed is "specific sectors & practices" with 3 % (19/613) of all articles. Less research was conducted within "Data management, sensing & monitoring" (8) and "specific regions" (7). No research was conducted within the knowledge domains "Living Labs & Lighthouses", "Science-based policy support", "Awareness, training & education" and "Institution & governance".

- **Existing research & knowledge**

The full corpus was analysed textually to review the themes addressed in the 613 articles. Overall, the main terms found in the articles are in descending order "organic matter", "soil water", "organic carbon", "bulk density", "water use efficiency", "crop growth", "soil layer" and "crop rotation". The map of the articles' textual content is presented in Figure 15. The main terms coalesce together in five clusters around the themes 1: "soil carbon", 2: "soil water", 3: "nutrient use efficiency", 4: "land use" and 5: "soil bulk density". There was little overlap between these clusters and some minor connectivity was evident between 4: "land use" and 1: "soil carbon", and 2: "soil water" and 3: "nutrient use efficiency".

The topic "increase biomass production" and ecosystem service "food, feed and fibre production" has been prominent down through the decades, especially from an agricultural perspective. The increased interest in the topic "increase biomass production" was accompanied by some change in the terms used and in the general areas of focus. Over time focus shifted from land use to land use change as well as from production agriculture to more focus on aspects of environmental impact. Attention also moved from soil nutrient availability and crop response to nutrient use efficiency and effects of fertilizer applications on the crop and environment. Interest in soil carbon increased, especially from 2000 to 2020 with more recent research using the terms soil organic carbon and carbon sequestration.

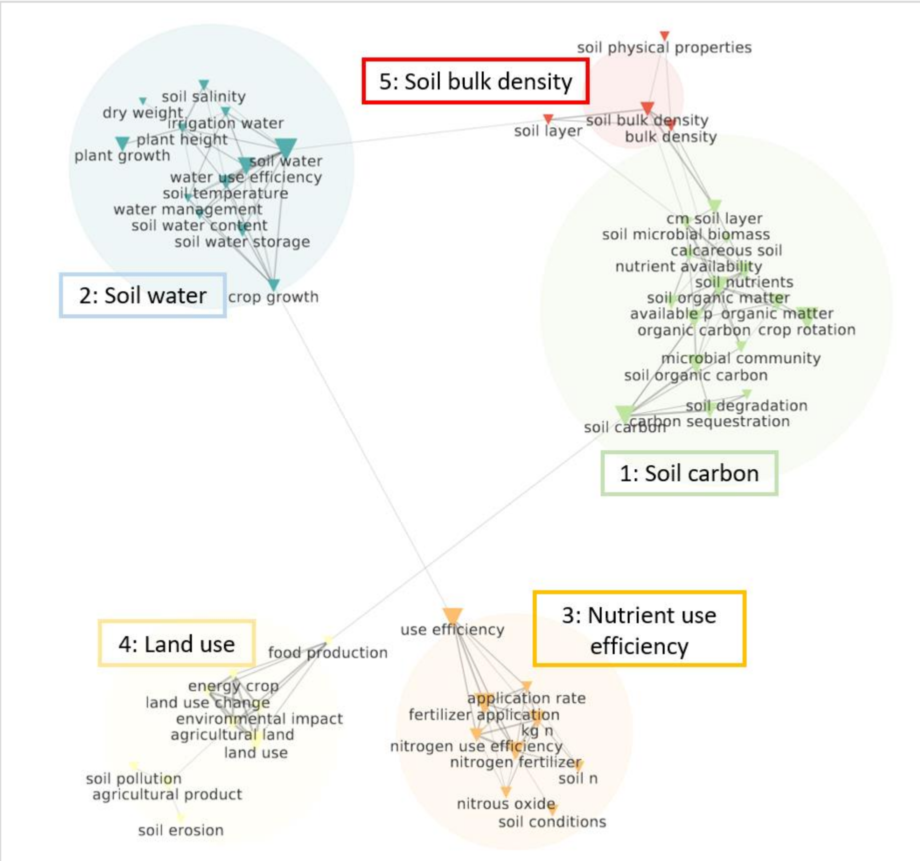


Figure 15: Overall cluster map of the main terms used in the 613 articles

- **Main actors publishing on the topic**

Almost one third of all articles (174/613, 28 %) were carried out in China (Figure 17). A substantial proportion of the articles were also conducted in the United States (115/613, 19 %). In Europe, the United Kingdom followed by Germany and the Netherlands are the countries who published the most articles (respectively 5 %, 4 % and 3 %). Four European institutions were involved in the production of at least 5 distinct articles each on the topic (Figure 16). The main institutions involved in Europe are Wageningen University & Research (Netherlands) and Sveriges lantbruksuniversitet (Sweden), with respectively 11 and 8 articles.

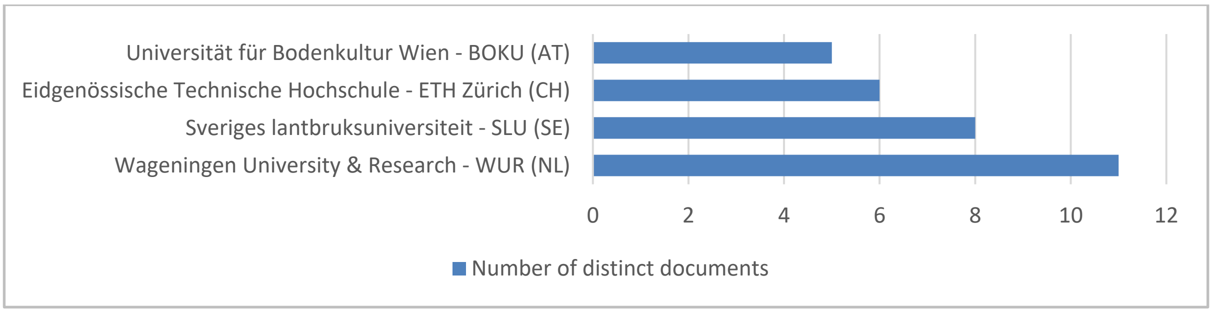


Figure 16: Main institutions in Europe who published more than 5 articles

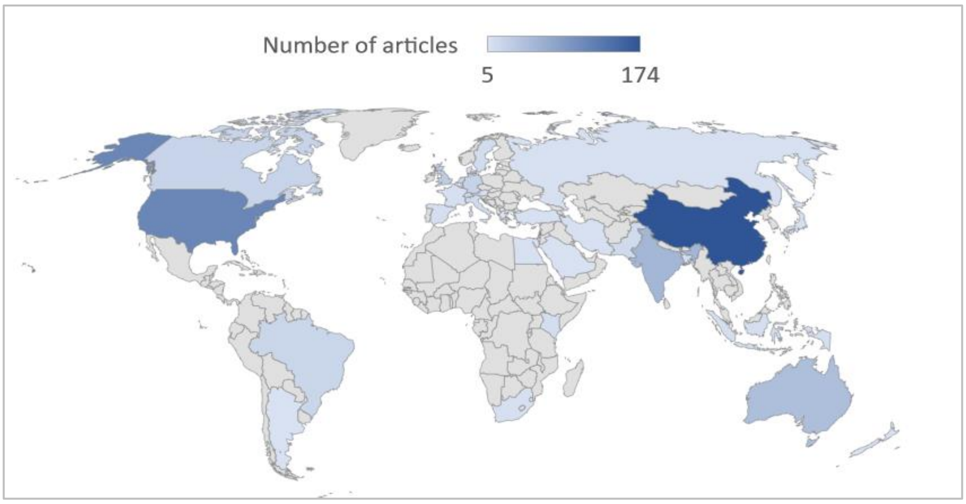


Figure 17: Map representation of the countries where at least 5 articles were published

Knowledge domain: Living Labs & Lighthouses
No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Living Labs & Lighthouses" related to biomass production increase.

Knowledge domain: Technical, economic & social innovation
Three articles on Scopus spanning 2012 to 2018 cover varying topics within the area of "technological, economic & social innovation". Two main topic areas emerged based on the articles available: 1) technological innovations that contribute to increased crop yield and 2) economic and social external support for innovative processes involving non-wood forest products (NWFP). There has been a shift within topic 1 as one paper (Ketterings et al., 2012) focused on increasing yield by determining critical values for nutrient (sulphur) requirements for alfalfa while a more recent paper (Nin et al., 2018) within the same topic area focused on yields associated new soilless production systems for strawberries.
Two of the three articles were published within Europe by CREA, the University of Florence in Italy and the University of Natural Resources and Life Sciences in Austria. The third article was published at Cornell University in the United States of America.

Knowledge domain: Data management, sensing & monitoring
Eight articles (from 2012-2018) with a focus on "data management, sensing & monitoring" exist on Scopus. The main focus of articles within this area involves using remote sensing and modelling to optimize crop growth in very diverse ways. A diversity of challenges including detecting heavy metal stress (Tian et al., 2017), creating a decision support tool (DST) for irrigation management (Paraskevopoulos et al., 2014) and the potential to increase crop productivity (Neumann et al., 2018) were investigated. The topic interest is persistent over time and the tool that is remote sensing continues to be adapted and applied to a wide range of challenges.
These articles are published each from different countries including the University of Natural Resources and Life Sciences in Austria, the South African Sugar Cane research institute (SASRI) in South Africa and the China University of Geoscience in China.

Knowledge domain: Assessment & modelling

- **Interest in the topic**

There is a total of 124 articles on Scopus relating to "assessment & modelling" published between 1983 and 2020. There was a significant increase in general attention in this area within the last years. 54 % (67/124) of the existing articles on the topic were published between 2016 and 2020. The number of articles being published reached 18 in 2020.

- **Existing research & knowledge**

The common terms fall into one of seven main clusters: 1: "Land use", 2: "Soil carbon", 3: "Soil water", 4: "Soil microbial", 5: "Soil amendments", 6: "Reinforced soil" and 7: "Time series analysis". There was a great deal of overlap and interconnectivity between the clusters of terms (Figure 18) relating to 2: "Soil carbon" and 4: "Soil microbial" with slightly less overlap between the clusters of terms 2: "Soil carbon" and 5: "Soil amendments". There was no overlap between the remaining four clusters of terms but there is some connectivity between 3: "Soil water" and 7: "Time series analysis".

In the late 1990's there was a great deal of focus on terms such as "organic matter" and "soil microbial". Over time this has split into two separate more detailed focus areas, one area associated with each term, as organic matter is replaced by terms such as soil organic carbon and soil carbon and the term microbial community becomes more common within the last ten years. The topic of soil amendment which was prevalent in the early 2000's begins to integrate into the topic of soil carbon around 2010 and by 2015 it is fully integrated. Focus also moves from soil moisture and soil water in the early 2000's to soil moisture and plant growth by 2020. Attention to field experiments involving *Triticum aestivum* diminishes around 2005, and diverges into focus on soil moisture and plant growth as well as a new topic, fuel consumption and soil condition improvement which fully emerges by 2010.

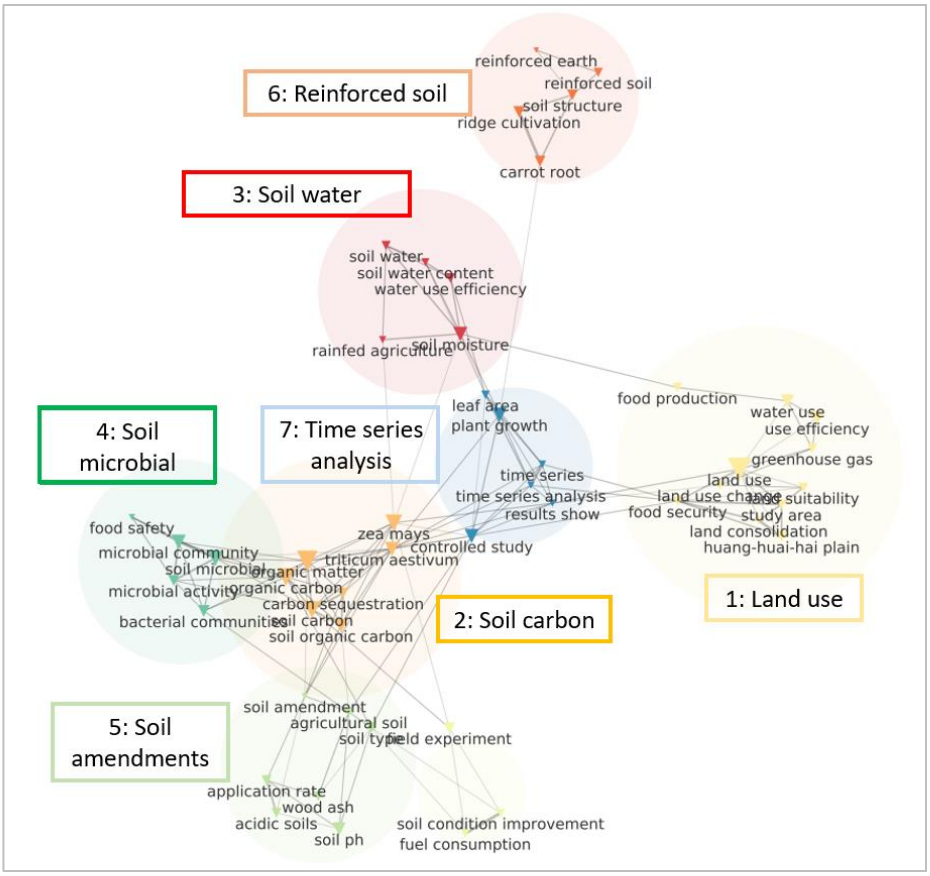


Figure 18: Cluster map of the main terms used in the full corpus (124 articles)

- **Main actors publishing on the topic**

China, the United States and the United Kingdom are the top three countries globally that publish the most articles in this area. The top countries in Europe are the United Kingdom, the Netherlands and France with respectively 11, 8 and 7 articles. Worldwide, the main institutes publishing on this topic are the Chinese Academy of Agricultural Sciences (China) and Wageningen University & Research (Netherlands). In China there is greater connectedness between publishing authors and groups of publishing authors compared to other countries where there are smaller groups of authors who are connected with each other but not with other groups.

Knowledge domain: Awareness, training & education

No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Awareness, training & education" related to biomass production increase.

Knowledge domain: Science-based policy support

No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Science based policy support" related to biomass production increase.

Knowledge domain: Institution & governance

No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Institution & governance" related to biomass production increase.

Knowledge domain: Specific regions

Seven articles (from 2007 - 2020) relating to biomass production increase with a focus on specific regions exist on Scopus. Less than half of the existing articles on the topic (3/7, 43 %) were published in the past last five years (2016-2020).

Among the seven articles, two, two, and three articles have a focus on respectively Mediterranean regions, boreal forests and islands & coastal areas. Regarding Mediterranean regions, one article evaluates the effect of cover crops on the direct emission of N_2O, CO_2 and CH_4 from soil in Mediterranean arable systems. Another article assesses the combined use of compost and wood scraps to increase biomass production in intensive farming systems in Italy. Among the two articles concerning boreal forests focus is set on (1) the addition of biochar to acidic boreal podzolic soils to enhance crop productivity; (2) the effect of paludification on wood biomass. The three articles related to islands & coastal areas all explore practices to enhance biomass production, such as the use of biochar or compost.

Canada is the country who published the most on the topic related to the boreal forests, whereas United States published the most on coastal areas / islands.

Knowledge domain: Specific sectors & practices

19 articles (from 1992 - 2020) relating to biomass production increase with a focus on specific sectors & practices exist on Scopus. Half of the existing articles on the topic (10/19, 53 %) were published in the past last five years (2016-2020).

Intercropping was the main focus. Nine articles were published in relation to this topic over the time period 1992 to 2020. Articles published between in 1992 and 2005, examined the introduction of different crops into specifically monoculture systems with an aim to increase yield. More recent articles published in 2019 and 2020 on intercropping specifically investigate nutrient management with a focus on nitrogen and leguminous crops as well as changes within the rhizosphere. Another, less dominant, topic area was organic amendments to soil to increase fertility and productivity. A total of four articles were published on the topic. Older articles published in 2000 and 2011 focused on compostable materials and straw in cooperation while more recent studies published within the last five years (2017 and 2020) investigated the use of biochar or bio-organic fertilizers. Various articles on land management strategies such as soil conservation, no-tillage, contour farming and cover crops were also present in this section and were published between 1999 and 2020.

China is the country with the most publications in this section from a range of different universities including China Agricultural University. Other countries with at least two publications in this section include Brazil, India and the United States. In Europe, Spain contributed the most. Most of the institutions have published only one article.

Knowledge domain: Basic knowledge production

There is a total of 465 articles on basic knowledge production not related to any knowledge domain and in relation to biomass production increase. These are articles were published between 1955 and 2020. There was a significant increase in general attention in this area within the last years. 51 % (236/465) of the existing articles on the topic were published between 2016 and 2020. The number of articles being published increased each year and reached 70 in 2020.

Aside from climate change mitigation, the main terms found in the articles are “use efficiency”, “organic matter”, “organic carbon”, “soil water” and “winter wheat”. The map of the articles’ textual content is presented in Figure 19. The main terms used in the 465 articles are distributed in five clusters, 1: “Fertilizer application”, 2: “Soil organic carbon”, 3: “Soil water”, 4: “Bulk density” and 5: “Soil microbial”. Cluster 3: “Soil water” has only interconnectivities with cluster 4: “Bulk density”. Cluster 2 has interconnectivities with the clusters 1, 4 and 5.
Almost one third of all articles (128/465, 28 %) were carried out in China. A substantial proportion of the articles were also conducted in the United States (88 articles). In Europe, Germany followed by the United Kingdom are the countries who published the most articles (respectively 4 % and 4 %). The main institution involved in Europe is the Swedish University of Agricultural Sciences (Sweden) with 7 articles.

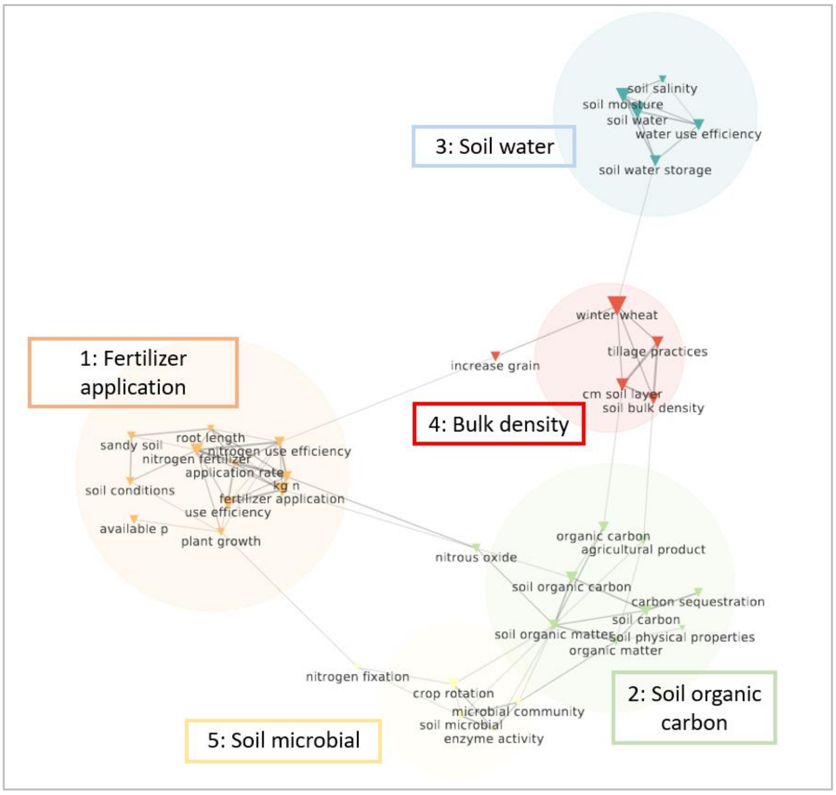


Figure 19: Cluster map of the main terms used in the full corpus (465 articles)

2. Societal challenge: mitigate land take

Knowledge domain: entire societal challenge

- **Interest in the topic**

67 scientific journal articles related to land take mitigation were identified. The 67 articles were published between 1982 and 2020. There has been a significant increase in general attention in this area since 2010 (Figure 20). 54 % (36/67) of the existing articles on the topic were published in the last five years between 2016 and 2020.

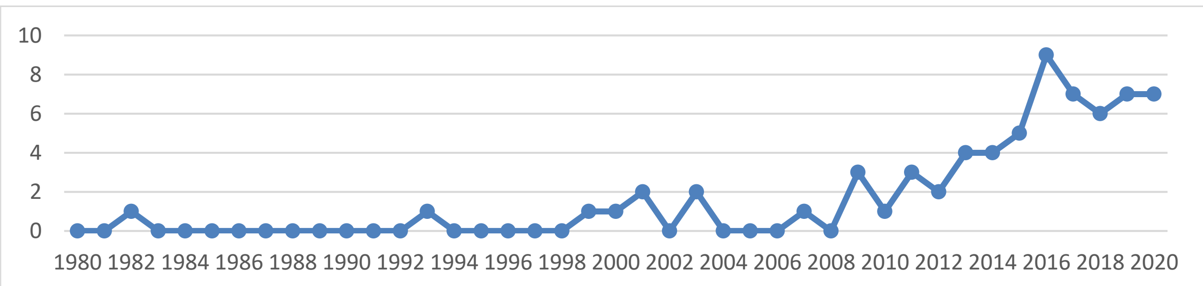


Figure 20: Chronologic number of articles since 1980 published on the topic “mitigate land take”

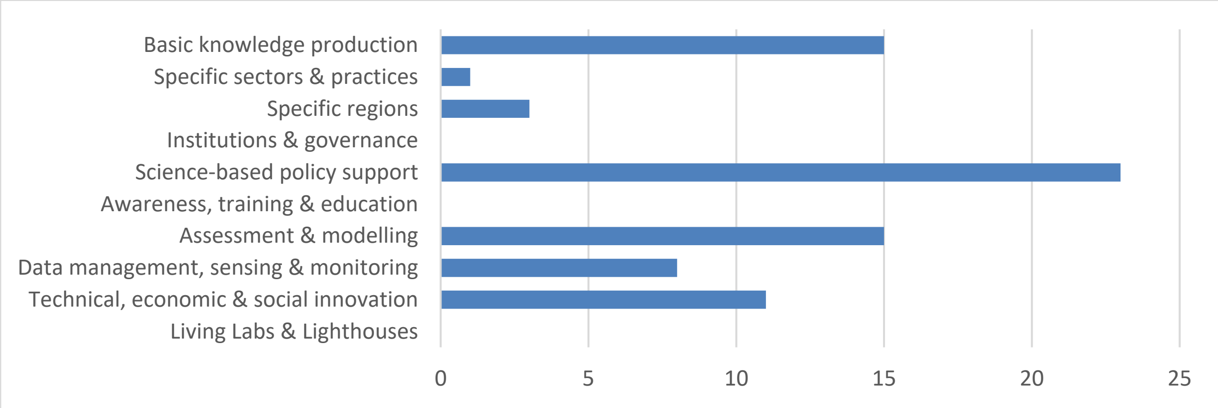


Figure 21: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 67 articles (Figure 21). One article can address several knowledge domains. A third of all articles (23/67, 34 %) have a focus on the knowledge domain "science base policy support". The other knowledge domain which is substantially addressed is "assessment & modelling" with 22 % (15/67) of all articles. 15 articles are basic knowledge production, not related to any particular knowledge domain (15/67, 22 %). Less research was conducted within "technical, economic & social innovation" (11). No research was conducted within "awareness, training & education", "institutions & governance" and "Living Labs & Lighthouses".

- **Existing research & knowledge**

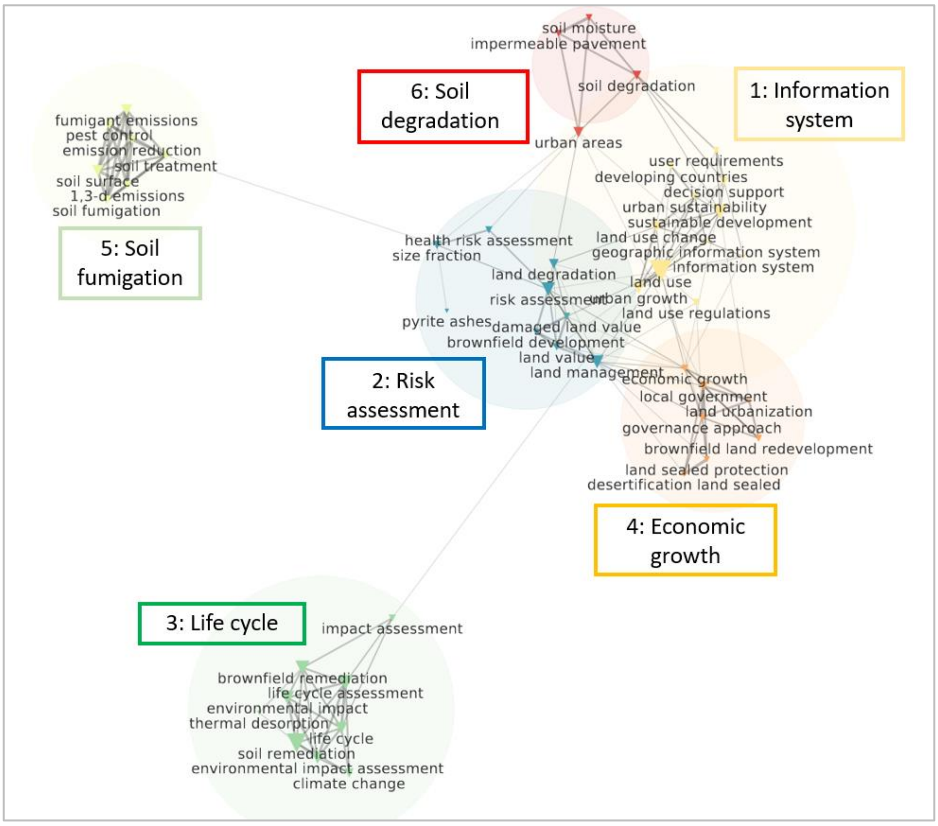


Figure 22: Overall cluster map of the main terms used in the full corpus (67 articles)

The full corpus was analysed textually to review the themes addressed in the 67 articles. Overall, the main terms found in the articles are "land use", "brownfield remediation", "soil remediation", "life cycle" and "risk assessment". The map of the articles' textual content is presented in Figure 22. The main terms coalesce together in six clusters around the themes 1: "information system", 2: "risk assessment", 3: "life cycle", 4: "economic growth", 5: "soil fumigation" and 6: "soil degradation". There are many interactions between the cluster 1: “information system” and the clusters 2: “risk assessment”, 4: “economic growth” and 6: “soil degradation”. The research on these terms is well covered and over time a change in the research topics can be observed. In the early 2000s, concerns were mostly on decision support & sustainable development, whereas in the late 2000s and currently, most articles focus on urban growth & sustainability.

- **Main actors publishing on the topic**

Half of all articles (34/67, 51 %) were equally carried out in the United States and China (Figure 23). In Europe, Germany followed by Italy, Spain and France are the countries who published the most articles (respectively 10 %, 7 %, 7% and 7 %). There are 23 communities of authors, represented by clusters (Figure 25). Authors tend to publish in small communities of authors with no interactions with different communities of authors. Six European institutions were involved in the production of at least two distinct articles each on the topic (Figure 24). The main institutions involved in Europe are Helmholtz Zentrum für Umweltforschung (Germany) and Universidad de Cantabria (Spain), with each 3 published articles.

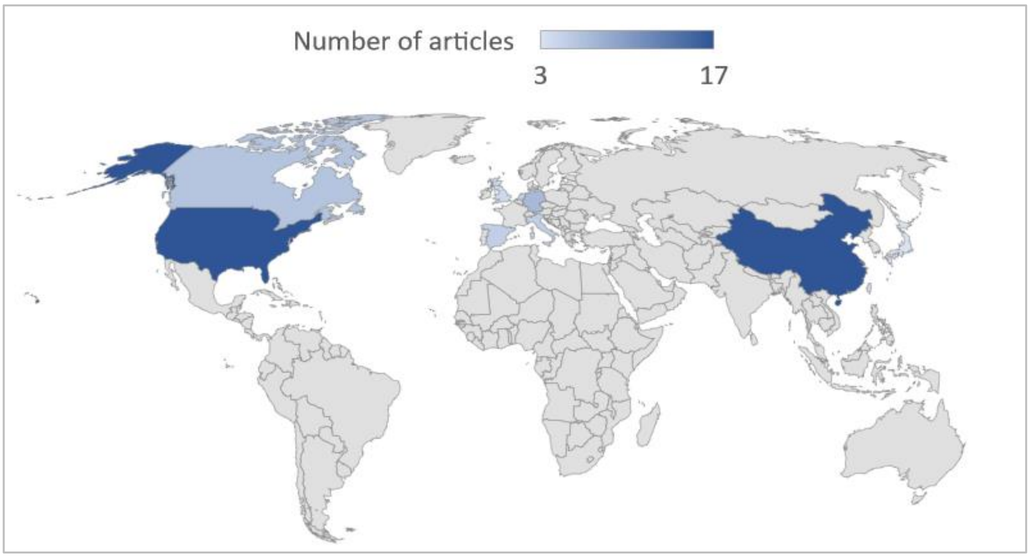


Figure 23: Map representation of the countries where at least 3 articles were published

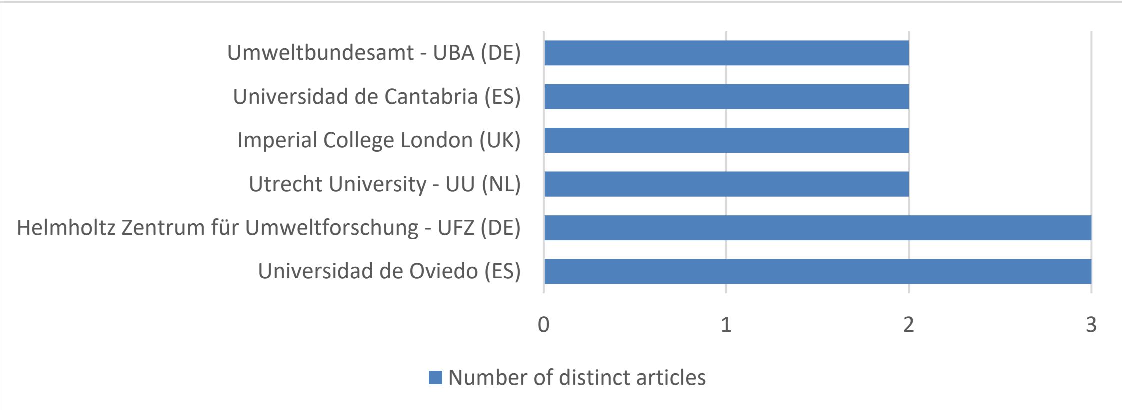


Figure 24: Main institutions in Europe who published more than 2 articles on the topic

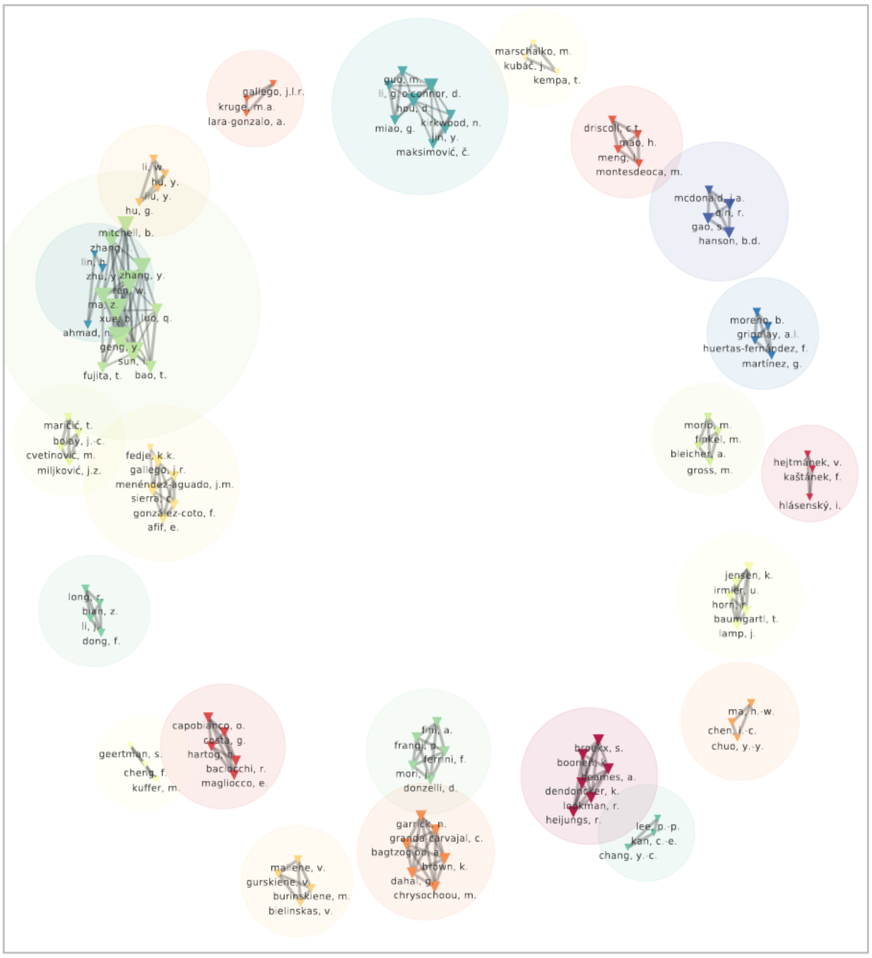


Figure 25: Map representing the interconnectivities between the main authors

Knowledge domain: Living Labs & Lighthouses

No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Living Labs & Lighthouses" related to land take mitigation.

Knowledge domain: Technical, social & economic innovation

Eleven articles relating to land take mitigation with a focus on "technical, economic & social innovation" exist on Scopus. They were published between 2003 and 2020. More than a third of the existing articles on the topic (4/11, 36 %) were published in the last five years (2016-2020).

The articles directly address the issue of sealing and desealing and possible technical options, like permeable pavements and sustainable urban drainage systems. There is a dominant cluster focusing on remediation of brownfield sites, with reference to various remediation types, contaminants, risk assessment and vulnerability of receiving environments. Secondly, environment issues are addressed, among which climate change, carbon foot print, and flooding, and environmental protection in general.

Most authors are from China (11), followed by the United States (4), and Germany (3). There is no specific organization with multiple publications in this field.

Knowledge domain: Data management, sensing & monitoring

Eight articles relating to land take mitigation with a focus on "data management, sensing & monitoring" exist on Scopus. They were published between 1999 and 2019. About two third of the existing articles on the topic (5/8, 63 %) were published in the last five years (2016-2020).

The main terms found in the articles can be grouped around two key clusters: (i) Methodological aspects, here the following innovative methods are mentioned such as geographic information systems, crowd sourcing, machine learning, problem-based learning, multi criteria analysis, signal encoding and spatio-temporal analysis; (ii) Spatial planning. Most terms concern urbanisation, urban planning, densification and urban re-

newal. Over time a change in the research topics can be observed. Articles from early 2000s focus on brownfield redevelopment. Whereas articles in the late 2000s focus on protection of soils by reducing land take at a larger scale, being regional, national or even European. Innovative monitoring methods like crowd sourcing or satellite data are also mentioned.
Most publications are from Chinese research organisations (4 articles) and by research and data management organisations of the European Union such as the Joint Research Center JRC and the European Environment Agency EAA (3 articles in total).

Knowledge domain: Assessment & modelling
15 articles relating to land take mitigation with a focus on "assessment & modelling" exist on Scopus. They were published between 1999 and 2019. More than half of the existing articles on the topic (9/15, 60 %) were published in the last five years (2016-2020).
In total four major thematic cluster were identified. The key thematic clusters are 1: "methodological aspects", 2: "environment and sustainability", 3: "spatial planning" and 4: "brownfield development". Regarding cluster 1: "methodological aspects", terms can be distributed in 3 categories referring to different types of methods: (i) Data evaluation methods like the Monte Carlo method, integer programming, uncertainty analysis and the weights of evidence method are mentioned; (ii) With regard to assessment methods, geographic information systems and life cycle assessment are referred to; (iii) prioritization methods and decision support systems and criteria analysis are mentioned. Cluster 2: "environment and sustainability" contains general terms like sustainable development and environmental protection, but also more specific terms referring to climate change, greenhouse gases, flood protection and mitigation of air pollution. Terms from cluster 3: "spatial planning" are mainly on urbanisation, land take and urban sprawl. In cluster 4: "brownfield development", terms focus on contamination, remediation and risk assessment.
Italy is worldwide the main publishing country followed by Germany and the Netherlands. No institution published more than one article on the topic.

Knowledge domain: Awareness, training & education
No articles were found. There are publications available for different target groups with the aim to raise awareness or educate specific target groups. Such material however, is usually not subject to peer reviewed scientific literature.

Knowledge domain: Science-based policy support
23 articles relating to land take mitigation and "science-based policy support" exist on Scopus. They were published between 1982 and 2020. About half of the existing articles on the topic (11/23, 48 %) were published in the last five years (2016-2020).
In total five major thematic cluster were identified, around which the main terms group. The key thematic clusters are 1: "spatial planning", 2: "specific regions", 3: "brownfield redevelopment & remediation", 4: "policy and decision making" and 5: "sustainability and environment". Regarding cluster 1: "spatial planning", terms like "urban sprawl", "urban planning", "spill over effects" are very dominant, followed by terms referring to spatial planning tools like "zoning", "land use planning" or infrastructure planning". Cluster 2: "specific regions" contains articles with a geographical reference, meaning they refer to a specific city or region. Articles referring to Chinese and European case studies are clearly dominating. Cluster 3: "brownfield redevelopment & remediation" concerns polluted sites. Cluster 4: "policy and decision making" is also a dominant cluster. Institutional and regulatory frameworks are assessed and recommendations for improvement made. In cluster 5: "sustainability and environment", the term sustainable development is dominant followed by environmental protection and ecosystem services.
Older articles focus on brownfield remediation and specific cases. Whereas more recent articles have a more holistic approach. They assess the regional situation and the regional policy framework behind. Most recently global sustainable development goals (SDGs) are being introduced, here in particular SDG 11.3.
China is worldwide the main publishing country. In Europe, Germany published most articles on this subject. There is no specific research organization with multiple publishing on this topic.

Knowledge domain: Institutions & governance
No articles were found.

Knowledge domain: Specific regions

Three articles (from 2011-2016) relating to land take mitigation with a focus on "specific regions" exist on Scopus. All three articles describe study cases of brownfield redevelopment. The specific regions are in all cases former industrial regions. One article provides innovative policy insights on urban brownfield redevelopment to both governmental officials and related stakeholders so that they can make appropriate remediation actions (Ren et al., 2015). Another article suggests approaches to prioritise brownfield reclamation (Nogués et al., 2016). There is a low interest in the topic within the Scopus community and no emerging main R&I actors.

Knowledge domain: Specific sectors & practices

Only one article relating to specific "sectors & practices" with a focus on land take mitigation was found on Scopus. The article was published in 2000 by the University of Aberdeen in the United Kingdom. The article focuses on land ownership of brownfield sites and can be assigned to the real estate sector (Adams et al., 2000). There is a low interest in the topic within the Scopus community.

3. Societal challenge: mitigate climate change

Knowledge domain: entire societal challenge

- **Interest in the topic**

837 scientific journal articles related to climate change mitigation were identified. The 837 articles were published between 1995 and 2020. There has been a significant increase in general attention in this area since 2010 (Figure 26). 60 % of the existing articles on the topic were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reaches 137 in 2020.

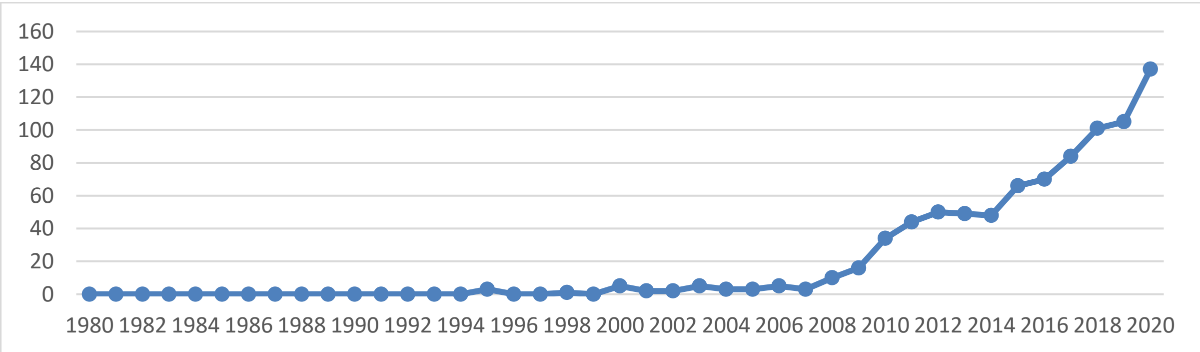


Figure 26: Chronologic number of articles since 1980 published on "mitigate climate change"

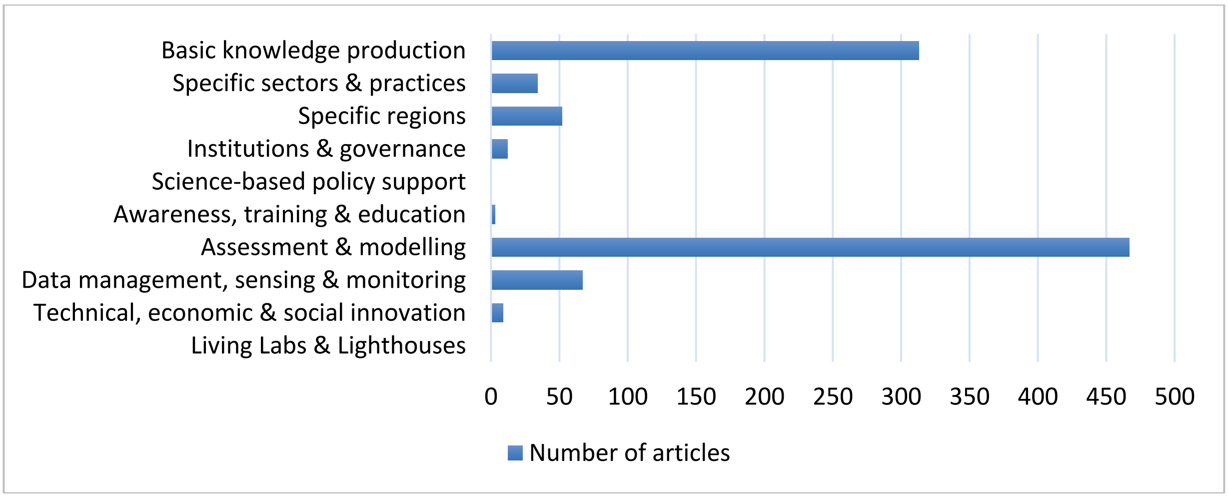


Figure 27: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 837 articles (Figure 27). One article can address several knowledge domains. More than half of all articles (467/837, 56 %) have a focus on the knowledge domain "assessment and modelling". Another knowledge domain which is substantially addressed is "data management, sensing & monitoring" with 8 % (67/837) of all articles. At least 313 articles are "basic knowledge production", not related to any particular knowledge domain (313/837, 37 %). Less research was conducted within "specific sectors and practices" (34) and "institutions and governance" (12). No research was conducted within "science-based policy support" and "Living Labs & Lighthouses".

- **Existing research & knowledge**

The full corpus was analyzed textually to review the themes addressed in the 837 articles. Overall, aside from climate change mitigation, the main terms found in the articles are "greenhouse gas emissions", "nitrous oxide and carbon dioxide", "land use change", "soil organic matter", "soil carbon sequestration", "life cycle", "impact assessment" and "soil management practices".

The map of the articles' textual content is presented in Figure 28. The main terms coalesce together in four clusters around the themes 1: "climate change mitigation", 2: "soil carbon", 3: "emission reduction" and 4: "N_2O & CO_2". There is an interaction between the cluster 1: "climate change mitigation" and the clusters 2: "soil carbon" and 3: "emission reduction". The research on these terms is well covered and over time a change in the research topics can be observed. In the early 2000s, concerns were mostly on land use change, whereas in the late 2000s and currently, most articles focus on reduction of greenhouse gas emissions and soil carbon sequestration. In addition, the interest for life cycle assessments decreased towards the later 2000s, whereas the interest increased for municipal solid waste management and nitrous oxide emissions.

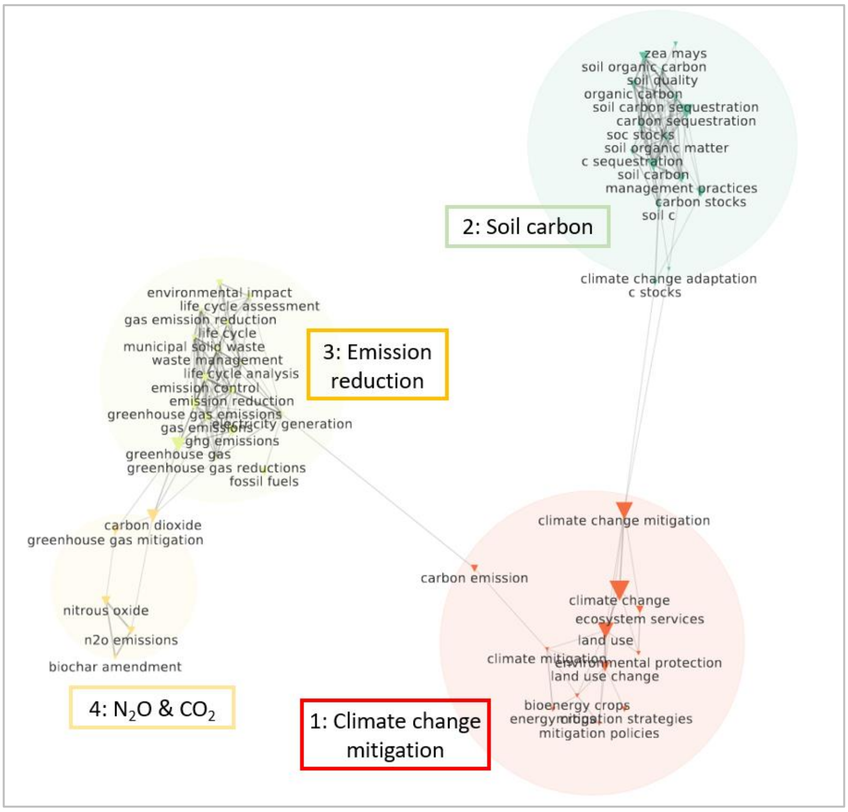


Figure 28: Overall cluster map of the main terms used in the 837 articles

Aside from the number of publications, the interest in climate mitigation over time can be illustrated by the increasing societal initiatives taken in the past years. In 1997, the Kyoto protocol was adopted after which the United Nations Framework Convention on Climate Change (UNFCCC) was launched. Through the protocol, the countries with the highest greenhouse gas emissions committed to emission reductions by implementation of mitigation policies and regularly reporting on their emissions. The Kyoto protocol was succeeded by the Paris Climate Agreement in which nearly all countries committed to a reduction of greenhouse gas emissions in order to limit global warming to 2°C, but preferably 1.5°C. One of the initiatives resulting from the Paris Climate Agreement is the ‘4 per 1000’ initiative in which it is strived for an annual increase of 0.4% in global soil organic carbon stocks. Furthermore, the knowledge in the Intergovernmental Panel on Climate Change (IPCC) reports provides the scientific basis for understanding climate change and the amount of greenhouse gas reductions required to reduce global warming. The IPCC reports therefore also provide the basis for climate change mitigation policies. An example of climate change mitigation in the socio-economic policy-making is the European Green deal which was formulated by the European Union as a reaction to the Paris Climate Agreement. Soil carbon sequestration plays an important role within this deal in the form of ‘carbon farming’ and it is expected that this will remain a scientific hot topic. In addition, the Food and Agricultural Organization of the United Nations (FAO) has recently launched the Global assessment of SOC sequestration potential (GSOCseq) programme to simulate the potential of soil carbon sequestration by providing training sessions in soil carbon data processing.

- **Main actors publishing on the topic**

Almost one third of all articles (238/837, 28 %) were carried out in the USA (Figure 29). A substantial proportion of the articles were also conducted in the United Kingdom (114/837, 14 %). In Europe, aside from the United Kingdom, Germany followed by the Netherlands and France are the countries who published the most articles (respectively 13 %, 7 % and 6 %). Nine European institutions were involved in the production of at least 15 distinct articles each on the topic (Figure 30). The main institutions involved in Europe are Wageningen University & Research (Netherlands) and Utrecht University (Netherlands), with respectively 31 and 23 articles.

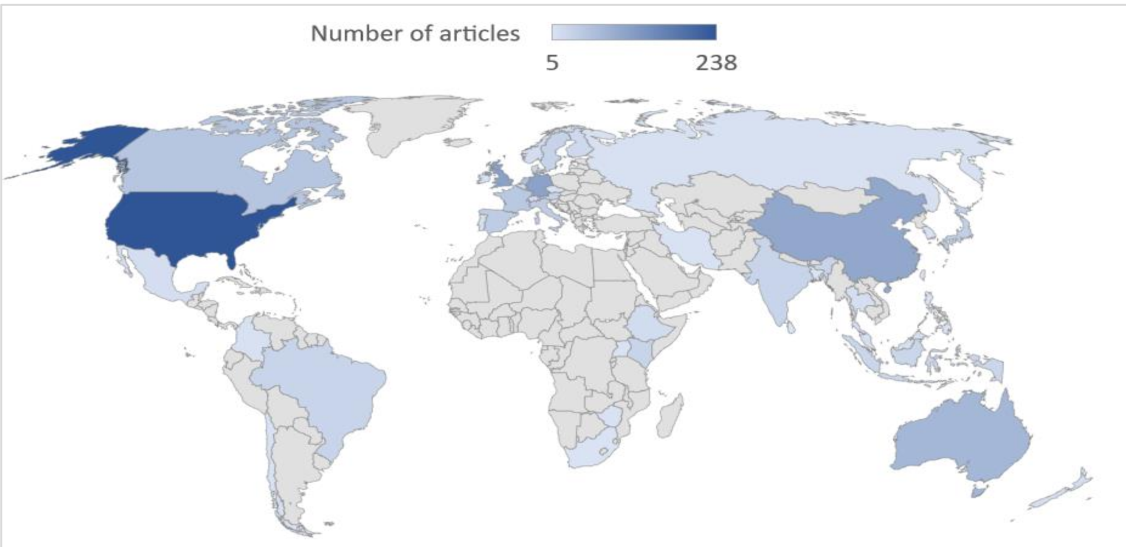


Figure 29: Map representation of the countries where at least 5 articles were published

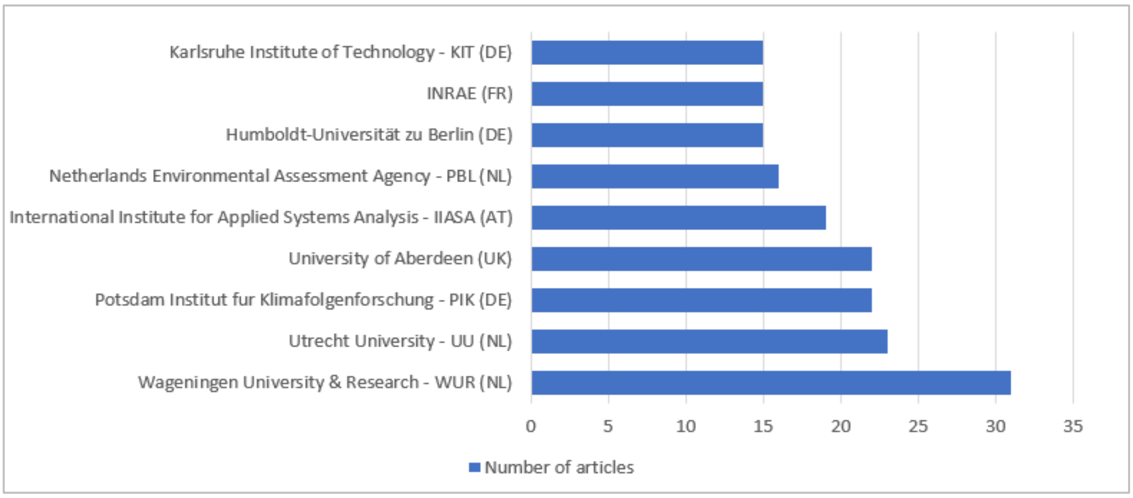


Figure 30: Main institutions in Europe who published more than 15 articles on the topic

There are 10 communities of authors (represented by clusters). 5 clusters have no interconnectivity with any other cluster (Figure 31). Authors from these clusters tend to publish in small communities of authors with no interactions with different communities of authors. Interconnectivities exist between the 5 other clusters, mainly with the author Smith P. (University of Aberdeen, United Kingdom) who publishes with various community of authors from 4 different clusters. Smith P. (University of Aberdeen, United Kingdom) and Popp A. (Potsdam institute for climate impact research, Germany) are the main authors in number of publications (respectively 21 and 16 publications), but there are about 40 authors with each 5 to 10 publications.

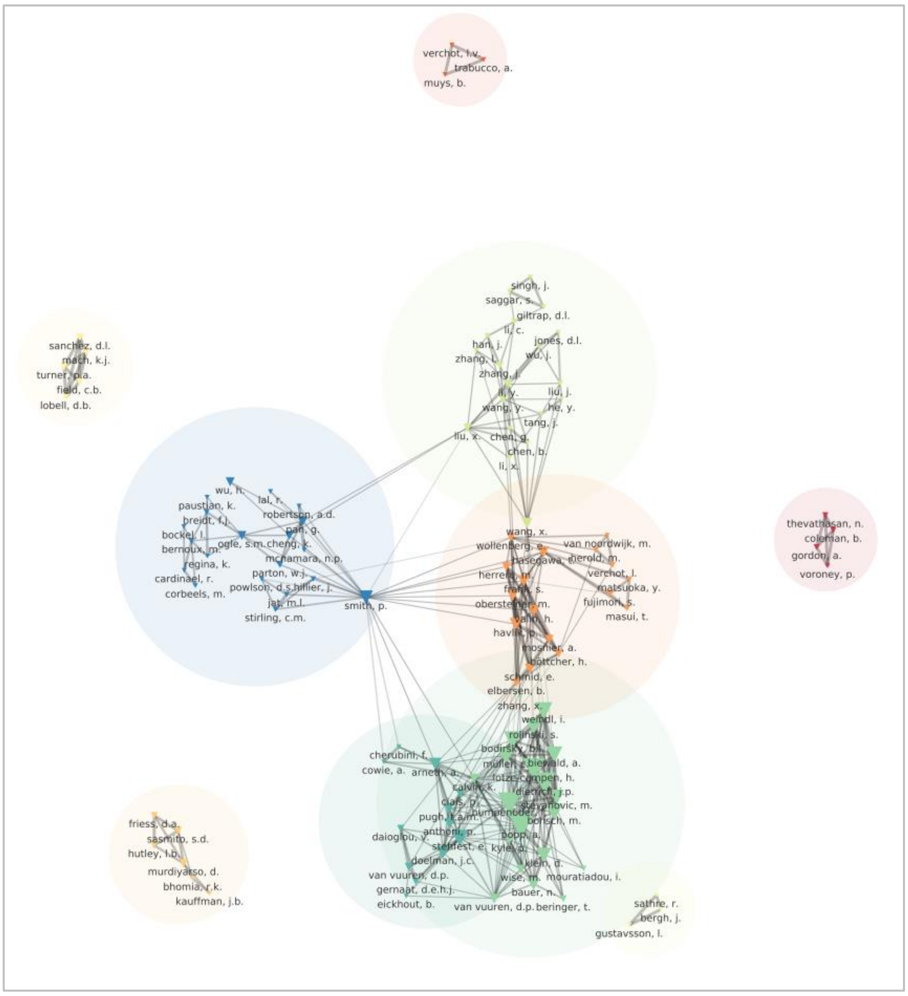


Figure 31: Map representing the interconnectivities between the main authors

Knowledge domain: Living Labs & Lighthouses

No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Living Labs & Lighthouses" related to climate change mitigation.

Knowledge domain: Technical, social & economic innovation

Nine articles relating to climate change mitigation with a focus on "technical, economic & social innovation" exist on Scopus. They were published between 2010 and 2020. Six articles focus on technical innovation, two on economic innovation and one on social innovation. Three of the six articles on technical innovation are on greenhouse gas removal, two on nitrous oxide and one on methane (Giltrap et al., 2010; Giltrap et al., 2011; Pratt et al., 2012). In addition, one article is on improving measurements of soil carbon fractions for climate change mitigation modelling (Gray et al., 2019), one is on the investigation of the soil carbon sequestration potential in perennial pastures (Pauli et al., 2018) and the final one is on the trade-offs between milk production and soil organic carbon storage (Kirschbaum et al., 2017). The two articles related to economic innovation include research on cost-effective and equitable forest conservation incentives and research on the valuation of the snow albedo effect (Börner et al., 2016; Lutz et al., 2015). Finally, the one article focussing on

social innovation examines the co-benefits of urban policy interventions to reduce carbon emissions in New-Zealand (Howden-Chapman et al., 2020). In conclusion, there is limited knowledge on innovation in the context of climate change mitigation. However, the high number of articles on the innovative approaches for valuation of soil carbon sequestration outside the Scopus database indicate that economic innovation is being assessed fairly well. For example, one article[6] notes the high potential of including soil carbon sequestration in a ‘carbon economy’.
Worldwide, New Zealand has contributed to the publication of 5 out of 9 articles. In Europe, Germany has published 3 articles. The Landcare Research in New Zealand is the only institute which has published more than 1 article (5 articles).

Knowledge domain: Data management, sensing & monitoring

- **Interest in the topic**

There is a total of 67 articles on Scopus relating to “data management, sensing & monitoring” in relation to climate change mitigation. The articles were published between 1995 and 2020. More than half of the existing articles on the topic (35/67, 52 %) were published in the last five years (2016-2020).

- **Existing research & knowledge**

The main terms used in the 67 articles are “land use”, “soil (organic) carbon”, “carbon dioxide”, “nitrous oxide” and “methane emissions”. More specific terms used are “flux measurement”, “remote sensing data” and “biocover system”. Over time a change in the research topics can be observed. In the early 2000s, concerns were mostly on environmental protection, methane emissions and air pollutants, whereas in the late 2000s most articles focus on greenhouse gas emissions (including carbon dioxide, methane nitrous oxide emissions) flux measurements, land use and satellite imagery.
Regarding soils in the context of climate change mitigation, the articles on monitoring are mainly related to monitoring soil carbon stocks, soil carbon sequestration and greenhouse gas emissions. An article was published on estimating European soil organic carbon contents with Land Use and Coverage Area frame Survey (LUCAS) data (Panagos et al., 2013). The authors suggest that the relation between landscape features and soil properties can be assessed through the LUCAS data set. They emphasise that investments should be made into accessibility, transparency and explanation of uncertainties instead of investing to obtain the highest data resolution. Also, the authors note the increasing importance of (cheaper and more accurate) remote sensing in monitoring changes in soil organic carbon. Accurate data management can also help in developing and evaluating remote sensing techniques and soil carbon models.
The articles are not limited to technical assessments of data management, sensing and monitoring strategies. For example, an article explored how independent data could be gathered for transparent monitoring of greenhouse gas emissions in the land use sector and increasing stakeholder participation (Romijn et al., 2018). The authors recommend further investments in monitoring in order to sustain land-based greenhouse gas emission reduction programmes and improving datasets to increase stakeholder involvement. Besides the use of accurate data management being important for monitoring and developing remote sensing and models, accurate data management can also help in policy-making. According to one of the articles, data management can also improve policy-making by contributing to sustainable land use planning through regional mapping of the climate change mitigation potential in soils. The authors note that obtaining realistic estimations of soil organic carbon stocks on a small geographical scale is still in development.
Outside of the Scopus review, a report[7] from the European Joint Project (EJP) SOIL highlights the high variety in the models and monitoring tools for monitoring of soil carbon stocks in Europe. The authors conclude that efforts of European countries to improve the monitoring systems could help to unify the methodology for

[6] Keenor, S. G., Rodrigues, A. F., Mao, L., Latawiec, A. E., Harwood, A. R., & Reid, B. J. (2021). Capturing a soil carbon economy. *Royal Society open science*, *8*(4), 202305.
[7] Astover, A., Escuer-Gatius, J. & Don Armolaitis, K. (2021). Inventory of the use of models for accounting and policy support. Retrieved from https://ejpsoil.eu/about-ejp-soil/news-events/item/artikel/accounting-and-monitoring-soil-quality-and-soil-carbon-stocks/

national greenhouse gas inventories and consequently climate change mitigation. Moreover, a synthesis review by Smith et al. (2019)[8] reviewed the existing monitoring systems for soil carbon as well and found that international cooperation should be promoted between countries with advanced monitoring systems and those without. The authors point out that the GSOCseq programme has been established to do so and work towards complete monitoring, reporting and verification (MRV) platforms for soil carbon changes.

- **Main actors publishing on the topic**

One third of all articles (22/67, 33 %) were carried out in the United States. A substantial proportion of the articles were also conducted in the United Kingdom (9/67, 13 %). In Europe, Germany is the country who published the most articles (12 %). Denmark Tekniske Universitet in Denmark is the institution in Europe who contributed the most (3 articles).

Knowledge domain: Assessment & modelling

- **Interest in the topic**

There is a total of 467 articles on Scopus relating to "assessment & modelling" in relation to climate change mitigation published between 1995 and 2020. 58 % (273/467) of the existing articles on the topic were published between 2016 and 2020. The number of articles being published increased each year and reached 60 in 2020.

- **Existing research & knowledge**

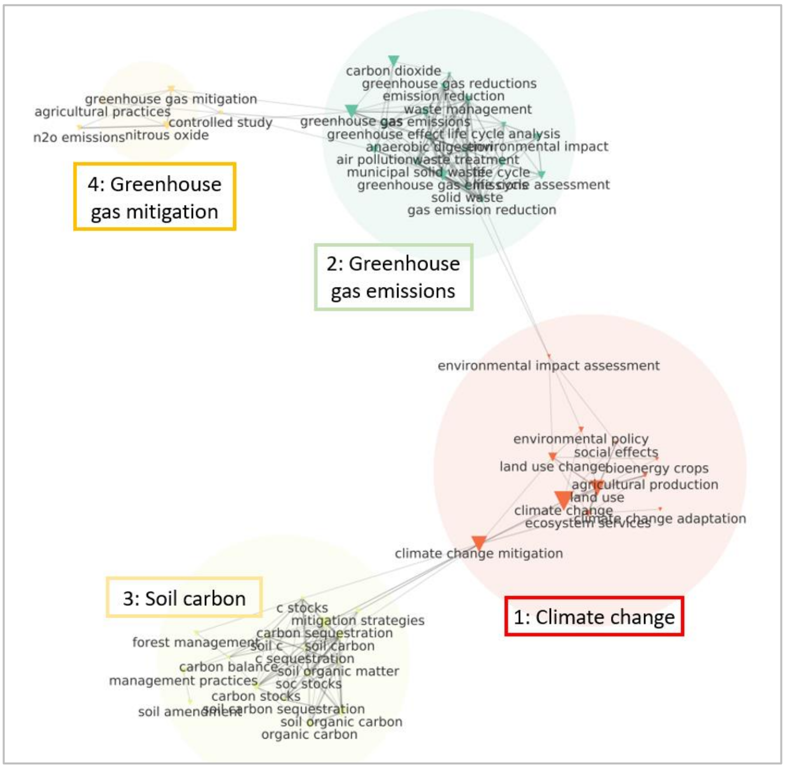


Figure 32: Cluster map of the main terms used in the full corpus (467 articles)

Aside from climate change mitigation, the main terms found in the articles are in descending order "land use change", "greenhouse gas emissions", "soil (organic) carbon", "life cycle assessment" and "management practices". Over time a change in the research topics can be observed. In the early 2000s, concerns were

[8] Smith, P., Soussana, J. F., Angers, D., Schipper, L., Chenu, C., Rasse, D. P., & Klumpp, K. (2020). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology*, *26*(1), 219-241.

mostly on land use change, whereas in the late 2000s most articles focus on greenhouse gas emissions (including nitrous oxide emissions) and soil carbon sequestration. In addition, the interest for solid waste management decreased towards the later 2000s, whereas the interest for life cycle assessments and environmental impact increased.
The map of the articles' textual content is presented in Figure 32. The main terms used in the 467 articles are distributed in four clusters, 1: "climate change", 2: "greenhouse gas emissions", 3: "soil carbon", 4: "greenhouse gas mitigation". No clear interaction between the cluster 4: "greenhouse gas mitigation" with the clusters 3: "soil carbon" and 1: "climate change" is observed. The clusters 3: "soil carbon" and 2: "greenhouse gas emissions" are related to cluster 1: "climate change".

In the articles, the potential of climate change mitigation in managing soil carbon stocks has been assessed by using various types of models. The integrated (terrestrial carbon cycle) IMAGE model was used in several publications, including for quantification of the effectiveness of climate change mitigation through soil carbon sequestration in forest plantations and for exploration of land-based climate change mitigation within the Shared Socio-economic Pathways (SSP). Other types of models are the CO2FIX model applied in an article to simulate the biomass and soil carbon sequestration of indigenous agroforestry systems, and the DayCent model applied in an article to simulate soil carbon sequestration and greenhouse gas mitigation potentials from rice croplands in Bangladesh. Another article focusses on the use of S-World modelling to derive global soil conditions under natural vegetation in order to improve future estimations of the soil carbon sequestration potential (Stoorvogel et al., 2017). Besides modelling soil carbon pools and sequestration, life cycle assessments (LCA) were also conducted. An LCA was for example used to calculate the soil carbon sequestration and greenhouse gas emissions in different rice cropping systems in Bangladesh. The articles related to Assessment & Modelling in the context of climate change mitigation suggest that soil carbon models and LCA methods should be improved to be able to reliably estimate on the sequestration potential in soil carbon pools over time.

- **Main actors publishing on the topic**

Almost one third of all articles (146/467, 31 %) were carried out in the USA (Fig. 4). A substantial proportion of the articles were also conducted in the United Kingdom (68/467, 14 %). In Europe, Germany followed by the Netherlands and France are the countries who published the most articles (respectively 14 %, 8 % and 7 %). 14 European institutions were involved in the production of at least 10 distinct articles each on the topic. The main institutions involved in Europe are Wageningen University & Research (Netherlands) and International Institute for Applied Systems Analysis (Austria), with respectively 20 and 16 articles. The main authors are P. Smith (Institute of Biological and Environmental Sciences & Climate Change, University of Aberdeen) (13) and A. Popp (Potsdam Institut fur Klimafolgenforschung) (11).

<u>Knowledge domain: Awareness, training & education</u>

Three articles (from 2015-2020) relating to climate change mitigation with a focus on "awareness, training & education" exist on Scopus. The scope of the 3 articles differ. The first article relates to "Awareness, training & education" because it addresses their role in climate change mitigation strategies by e.g. creating more awareness in focus group discussions (Ngonyani et al., 2019). The second article addresses the history of the impact of social factors on the implementation of environment friendly techniques (EFTs) and relates to awareness by describing the impact of cultural factors on implementing EFTs for climate change mitigation (Hălbac-Cotoară-Zamfir, 2019). The third article relates to awareness by using interviews with local people on their motivations to participate in a Reducing Emissions from Deforestation and Forest Degradation-Plus (REDD+) project (Harada et al., 2015). Considering the small number of articles on the topic, there is no emerging main R&I actors.

<u>Knowledge domain: Science based policy support</u>

No articles were found. We can conclude that there is no existing knowledge on Scopus regarding "Science-based policy support" related to climate change mitigation.

Knowledge domain: Institutions & governance

Twelve articles (from 2012-2020) relating to climate change mitigation with a focus on "institutions & governance" exist on Scopus. 92 % of the existing articles on the topic (11/12) were published in the last five years, between 2016 and 2020.

One of the articles related to policy-making aims to evaluate the relation between Large Scale Land Acquisitions (LSLA) and Reducing Emissions from Deforestation and forest Degradation (REDD+) (Carter et al., 2017). This article illustrates the conflicts that might occur between climate change mitigation and agricultural production in the context of policy-making and governance. The articles related to land use planning assess land use in relation to agricultural soils emissions, conversion of forest to croplands or using croplands for bioenergy production. One of the articles related to an institutional framework and land use planning aims to investigate the use of Biomass Energy with Carbon Capture and Storage (BECCS) technologies in emission scenarios generated by model (Vaughan et al., 2018). The authors conclude that the amount of CO_2 removed by BECCS can be reduced by poor governance of the sustainability of bioenergy crop production due to soil carbon losses from direct and indirect land use change (e.g. when grassland is converted to arable land for bioenergy crops). In conclusion, the main focus of articles related to "Institutions & Governance" are soils in relation to land use (e.g. bioenergy production). However, the twelve articles cover a wide variety of research topics within "Institutions & governance".

Three articles were published in the United Kingdom and Germany, and two articles in Sweden. There are no main institutions involved in the production of more than one article on the topic. Considering the small number of identified articles on the topic, there is no emerging main R&I actors.

Knowledge domain: Specific regions

- **Interest in the topic**

52 articles (from 2010 - 2020) relating to climate change mitigation with a focus on specific regions exist on Scopus. Two thirds of the existing articles on the topic (35/52, 67 %) were published in the past last five years (2016-2020).

- **Existing research & knowledge**

The main specific terms used are "land degradation", "eddy covariance systems", "peatland restoration", "Kyoto protocol" and "water availability". Over time a change in the research topics can be observed. In the period 2010-2015 concerns were mostly on water availability (in the Mediterranean basin), whereas in the period 2016-2020 most articles focus on greenhouse gas emissions, soil organic carbon and carbon storage.

Most articles which mention a specific region are about the Mediterranean basin (Greece, North-East Spain, Italy). The studies in the Mediterranean basin are for example on carbon emissions of different tillage practices, biochar additions based on agricultural residues and natural disturbances in boreal forests. A meta-analysis on Mediterranean croplands and carbon sequestrations explains the focus on the Mediterranean basin by relating this area with seasonally dry agroecosystems with low soil organic carbon stocks and high risk of land degradation and desertification (Aguilera et al., 2013). However, the authors suggest that the potential for soil carbon sequestrations in these systems is high. Another large analysis of available carbon sequestration potential data on Mediterranean agricultural soils has recommended a set of mitigation strategies including the use of local fertilizers such as residues or manure.

- **Main actors publishing on the topic**

The countries who are most active in publishing on this topic are, in descending order Spain, Germany, and Italy, with respectively 12, 10 and 9 articles each. The main institutions involved in Europe are Wageningen University & Research (Netherlands) and Consiglio Nazionale delle Ricerche (Italy), with each 4 articles. The number of articles published per author is mainly limited to one article. The authors with two articles on this topic are R. Farina (Council for Agricultural Research and Agricultural Economy Analysis – CREA, Italy) and E. Aguilera (Universidad Pablo de Olavide, Spain).

Knowledge domain: Specific sectors & practices

- **Interest in the topic**

34 articles (from 2005 - 2020) relating to climate change mitigation with a focus on specific sectors & practices exist on Scopus. Two thirds of the existing articles on the topic (23/34, 68 %) were published in the past last five years (2016-2020). The number of articles being published increased each year and reached 13 in 2020.

- **Existing research & knowledge**

In the years 2019-2020, most of the articles are related to agroforestry systems as carbon sequestration opportunities. In the early 2010s, a significant number of articles are also related to agroforestry and agroecological systems in general, but the topic is not necessarily limited to carbon sequestration (e.g. also relation with food production). A meta-analysis of studies on agroforestry in the humid tropics indicated that agroforestry can indeed enhance soil carbon sequestration and simultaneously reduce nitrous oxide and methane emissions. Therefore, the authors conclude that agroforestry is promising as a means to mitigate climate change. Aside from the humid regions, another meta-analysis of 78 peer-reviewed studies suggested that agroforestry is also promising in the arid and semiarid regions, but no effect could be found for the temperature regions (Chatterjee et al., 2018). However, both meta-analyses stress that there are inconsistencies in experimental design and missing explanatory variables which should be improved in further studies. Also, there are limited studies conducted under a variety of land-management scenarios, soil type and tree species.

- **Main actors publishing on the topic**

The countries who are globally most active in publishing on this topic are Spain and the United States. In the European Union, Spain and France contributed the most. Most of the institutions have published only one article. Similarly, the number of articles published per author is mainly limited to one article.

Knowledge domain: Basic knowledge production

There is a total of 313 articles not related to any knowledge domain and in relation to climate change adaptation. These are articles were published between 1995 and 2020. Aside from climate change mitigation, the main terms found in the articles are “gas emissions”, “land use”, “carbon sequestration”, “water conservation” and “effects of climate change”.

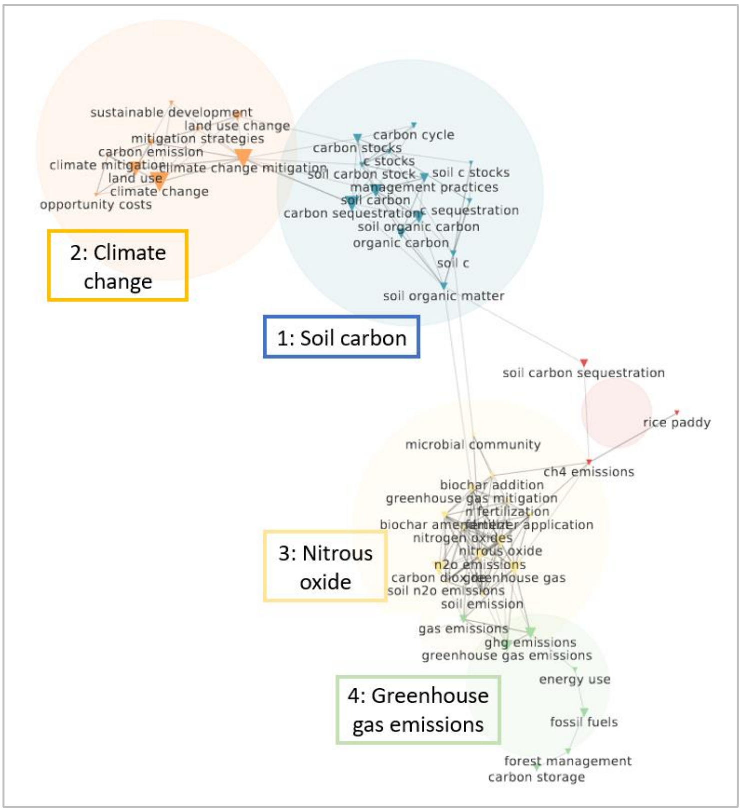


Figure 33: Cluster map of the main terms used in the full corpus (313 articles)

The map of the articles' textual content is presented in Figure 33. The main terms used in the 313 articles are distributed in four clusters, 1: "soil carbon", 2: "climate change", 3: "nitrous oxide", 4: "greenhouse gas emissions". Cluster 2 has only interconnectivities with cluster 1. Similarly, cluster 4 has only interconnectivities with cluster 3.
Almost one third of all articles (88/313, 31 %) were carried out in the USA. A substantial proportion of the articles were also conducted in China and in the United Kingdom (both 45 articles). In Europe, the United Kingdom followed by Germany and the Netherlands are the countries who published the most articles (respectively 14 %, 12 % and 5 %). The main institutions involved in Europe are University of Aberdeen (United Kingdom) and Swedish University of Agricultural Sciences (Sweden), with 8 articles each.

4. Societal challenge: adapt to climate change

<u>Knowledge domain: entire societal challenge</u>

- **Interest in the topic**

370 scientific journal articles related to climate change adaptation were identified. The 370 articles were published between 1990 and 2020. There has been a significant increase in general attention in this area since 2008 (Figure 34). 65% of the existing articles on the topic were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reaches 71 in 2020, as soils bear a great potential for adaptation of agriculture, forestry and urban sectors to climate change.

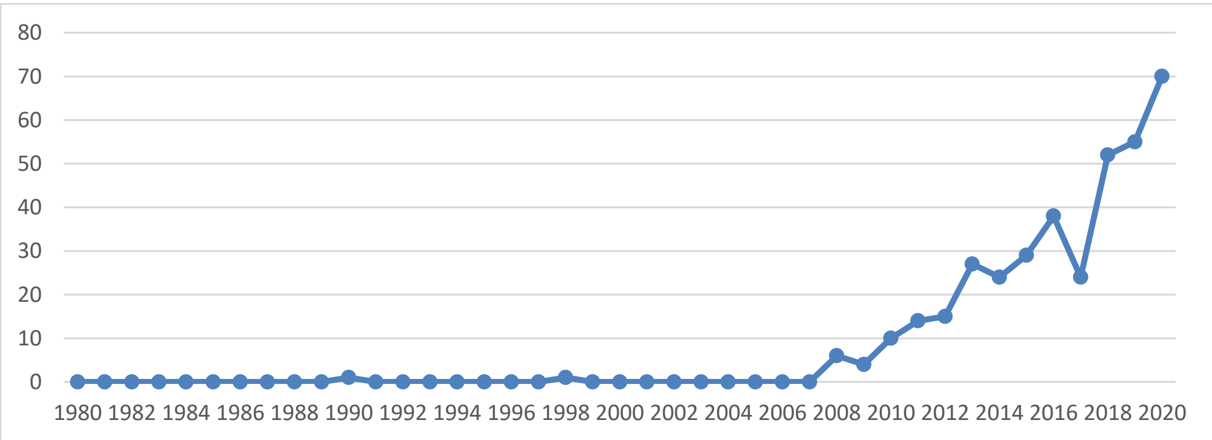


Figure 34: Chronologic number of articles since 1980 published on "adapt to climate change"

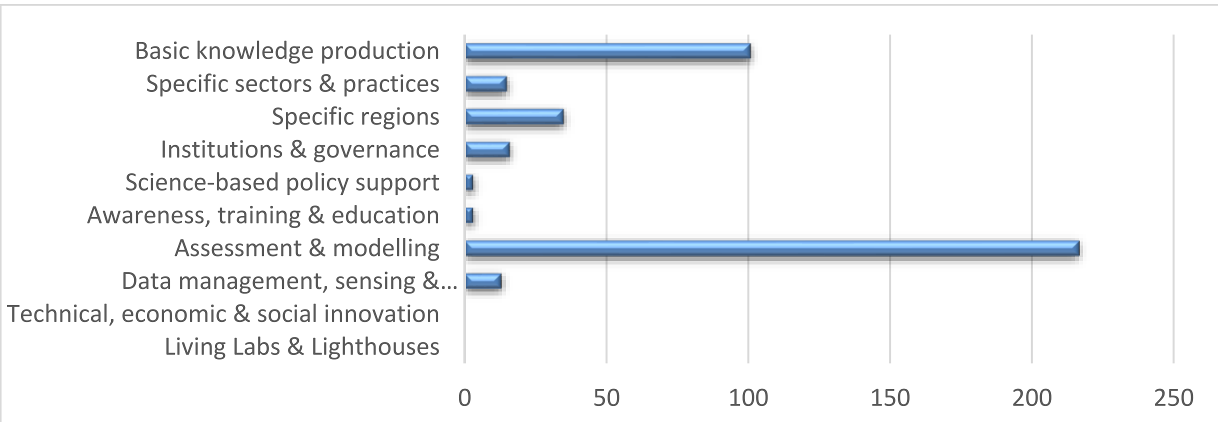


Figure 35: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 370 articles (Figure 35). One article can address several knowledge domains. More than half of all articles (217/370, 58%) have a focus on the knowledge domain "assessment and modelling". The other knowledge domain which is substantially addressed is “specific regions” with 10% of all articles. At least 101 articles are “basic knowledge production”, not related to any particular knowledge domain (101/370, 27%). Less research was conducted within “specific sectors and practices” (4 %) and “institutions & governance” (4 %). No research was conducted within “technical, economic & social innovation” and “Living Labs & Lighthouses”.

- **Existing research & knowledge**

The full corpus was analysed textually. Overall, aside from climate change adaptation, the main terms found in the articles are “land use”, “adaptation measures”, “land management”, “management practices”, “water resource” and “food security”. From 2000 to 2020, the main terms used in articles have not varied demonstrating of a similar focus throughout time. However, new terms have appeared in the last years such as soil organic carbon.

The map of the articles’ textual content is presented in Figure 36. The main terms used in the 370 articles are distributed in six clusters 1: “climate change adaptation strategies”, 2: “water stress”, 3: “soil carbon & soil fertility”, 4: “urban area & surface temperature”, 5: “forest management”, 6: “sea level”. The clusters have very few interconnectivities and no overlaps between them, except between the clusters of terms 1. and 4. on respectively “climate change adaptation strategies” and “urban area & surface temperature”, demonstrating a strong connection between those two topics. The cluster with the most interconnectivities with other clusters is the cluster 1. “climate change adaptation strategies” which interconnects with all clusters except from the clusters 3. “soil carbon & soil fertility” and 5. “forest management”.

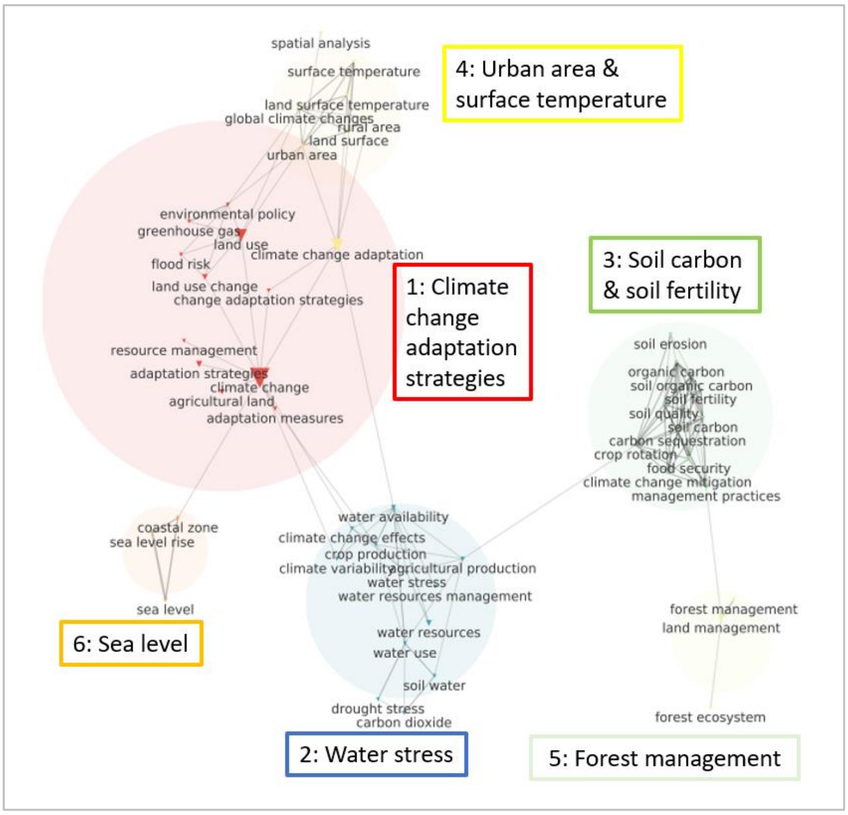


Figure 36: Overall cluster map of the main terms used in the full corpus (370 articles)

- **Main actors publishing on the topic**

Almost one third of all articles (119/370, 32 %) were carried out in the United States (Figure 37). A substantial proportion of the articles were also conducted in the United Kingdom (54/370, 15 %). In Europe, beside the United Kingdom, Germany followed by the Netherlands and Spain are the countries who published the most articles (respectively 11 %, 7 % and 6 %). Nine European institutions were involved in the production of at least 5 distinct articles on the topic (Figure 38). The main institutions involved in Europe are Wageningen University & Research (Netherlands) and Karlsruhe Institute of Technology (Germany), with respectively 16 and 8 articles.

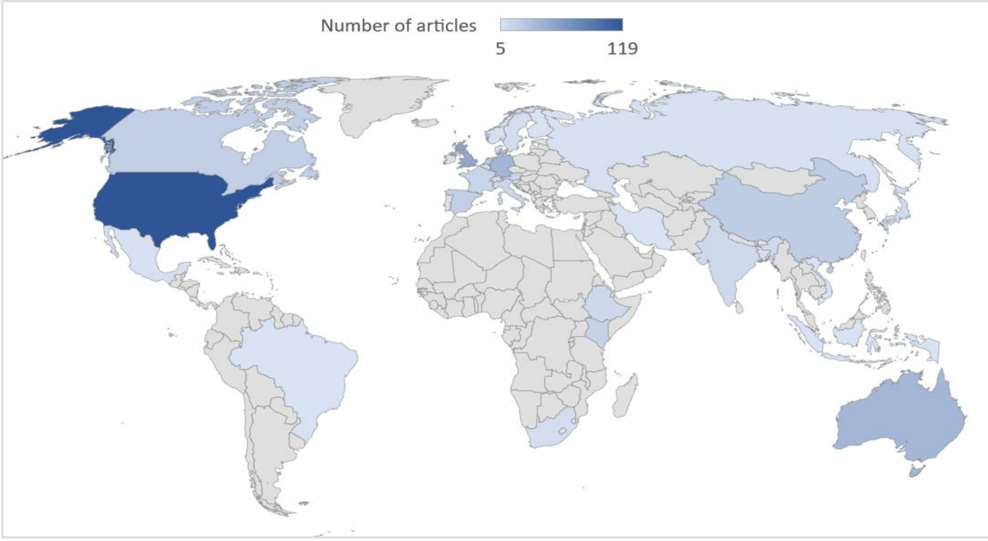


Figure 37: Map representation of the countries where at least 5 articles were published

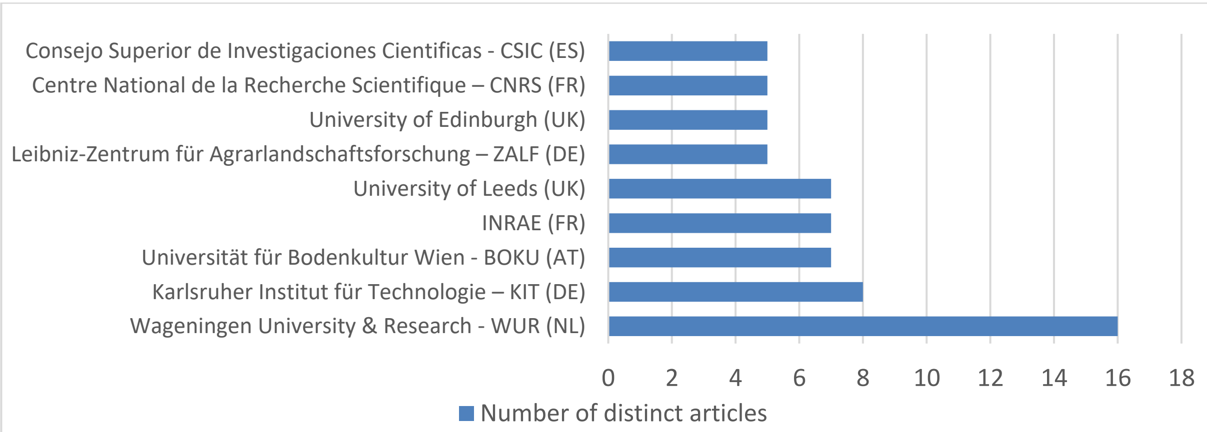


Figure 38: Main institutions in Europe who published more than 5 articles on the topic

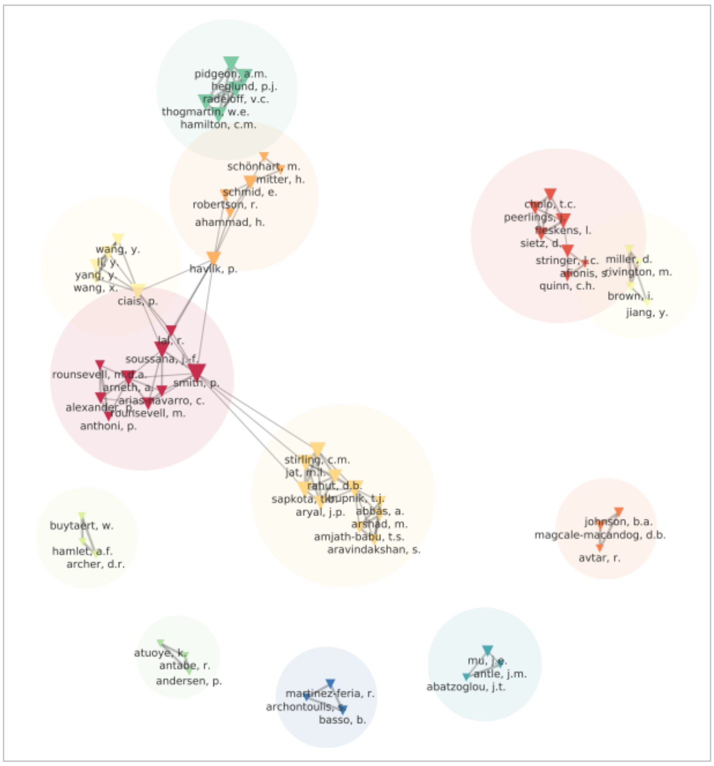


Figure 39: Map representing the interconnectivities between the main authors

There are 12 communities of authors (represented by clusters) with only one cluster having interconnectivity with 3 other clusters (Figure 39). Authors tend to publish in small communities of authors with scarce interactions between the different communities of authors. Lal R. (The Ohio State University, United States) and Stringer L. C. (University of Leeds, United Kingdom) are the main authors in number of publications (respectively 5 and 4 publication), but there are many authors with three, two or one publications.

Knowledge domain: Living Labs & Lighthouses

No articles were found. We can conclude that there is a no existing knowledge on Scopus regarding "Living Labs & Lighthouses" related to climate change adaptation.

Knowledge domain: Technical, social & economic innovation

No articles were found. We can conclude that there is a no existing knowledge on Scopus regarding "Technical, economic & social innovation" related to climate change adaptation.

Knowledge domain: Data management, sensing & monitoring

Thirteen articles relating to climate change adaptation with a focus on "data management, sensing & monitoring" exist on Scopus. They were published between 2011 and 2020. More than two thirds of the existing articles on the topic (9/13, 69 %) were published in the last five years (2016-2020).

The main focus of articles within this area involves using remote sensing and monitoring to adapt to climate change in very diverse ways. Five articles explore monitoring processes, as climate change adaptation progress in the context of natural resource management is not systematically monitored and tracked. Two of the articles describe monitoring programs for adaptation to climate change at the local municipality level, as a way to increase climate change resilience in agriculture (Burton et al., 2014; Anhalt-Depies, 2016). Two other articles give examples of the development of indicators for monitoring the implementation of measures and adaptation efficiency (Edel'geriev et al., 2020; Cvejić et al., 2019). Three articles look into the evolution of climate change adaptation measures by using remote sensing (Proctor et al., 2011 ; Kibret et al., 2020; Qiu et al., 2020).

Worldwide, the United States and the United Kingdom are the countries that published the most on the topic. Considering the small number of identified articles on the topic, there is no emerging main R&I actors.

Knowledge domain: Assessment & modelling

- **Interest in the topic**

There is a total of 217 articles on Scopus relating to "assessment & modelling" in relation to climate change adaptation published between 2008 and 2020. There was a significant increase in general attention in this area within the last years. 65 % of the existing articles on the topic were published between 2016 and 2020. The number of articles being published increased each year and reached 35 in 2020.

- **Existing research & knowledge**

Aside from climate change adaptation, the main terms found in the articles are "adaptation measures", "impact assessment", "land management", "adaptation options" and "climate models". Between 2008 and 2020, the main terms used in articles have not varied, thus demonstrating a similar focus throughout time. However, some new main terms have appeared in the last years such as "sea level rise", "flood control" and "soil carbon". The map of the articles' textual content is presented in Figure 40. The main terms used in the 217 articles are distributed in six clusters, 1: "land use", 2: "greenhouse gas", 3: "water stress", 4: "soil carbon", 5: "sea level", 6: "urban area & urban heat island". The clusters have very few interconnectivities and no overlaps between them, except between the clusters of terms for 1: "land use" and 3. "water stress". The cluster with the most interconnectivities with other clusters is cluster 1: "land use" which interconnects with all clusters except from clusters 4: "soil carbon" and 5: "sea level". It may be relevant to mention one articles (Holman et al., 2019) which reviewed the scientific literature to investigate conceptualisation and models of climate change adaptation, and the ways in which representation of adaptation in models can be improved.

- **Main actors publishing on the topic**

United States, United Kingdom, and Australia are the main publishing countries worldwide. In Europe, Germany followed by the Netherlands, France and Austria are the countries who published the most articles. Seventeen European institutions were involved in the production of at least 3 distinct articles on the topic. The main institutions involved in Europe are Wageningen University & Research (Netherlands), Karlsruhe Institute of Technology (Germany) and Universität für Bodenkultur Wien (Austria). Authors tend to publish in small communities of authors with scarce interactions between the different communities of authors. Stringer L. C. (University of Leeds, United Kingdom) and Schmid E. (Universität für Bodenkultur Wien, Austria) are the main authors in number of publications (4, 3), but there are many authors with one or two publications.

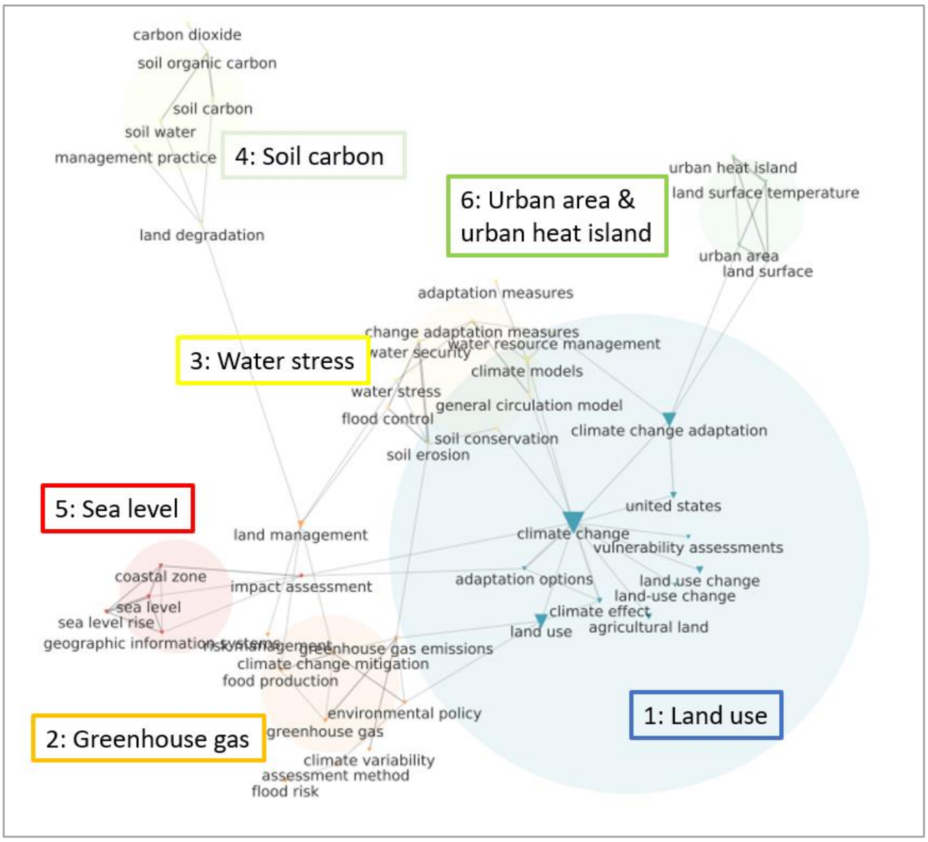


Figure 40: Cluster map of the main terms used in the full corpus (217 articles)

Knowledge domain: Awareness, training & education

Three articles (from 2009-2020) relating to climate change adaptation with a focus on "awareness, training & education" exist on Scopus. There is a low interest in the topic within the Scopus community.
The articles have either a focus on the awareness of farmers towards adaptation strategies, or on enhancing social learning among land managers. Two of the articles focus similarly on farmers' climate awareness and their perceptions regarding the change in climate patterns as well as their choices of farming practices to adapt to these changes. The articles provide evidence to support the design of capacity development interventions targeting specific groups of farmers according to their main crop and education profile (de Sousa et al., 2018; Thinda et al., 2020). The third article reflects on the use of deliberative workshops as an effective technique to enhance social learning regarding adapting to climate change (McCrum et al., 2009).
The institutions involved in the production of the articles are based in South Africa, the United Kingdom and Costa Rica. Considering the small number of identified articles on the topic, there is no emerging main R&I actors.

Knowledge domain: Science-based policy support

Three articles (from 2014-2016) relating to climate change adaptation with a focus on "science-based policy support" exist on Scopus. All three existing articles are case articles on ways to enhance science – policy partnerships towards climate change adaptation. In these three articles, perspectives for strengthening links among the scientific and policy-making communities are highlighted, and practical lessons learned are provided to help other decision-makers begin and amplify the process of integrating climate change into public policy and planning initiatives. The first article provides conceptual and practical guidance on bridging the science action gap through partnerships (Cockburn et al., 2016). The article emphasizes the importance of building collaborative capacity and social capital, and the importance of paying attention to the process of transdisciplinary research to achieve more tangible science, management, and policy objectives in science-action partnerships. The second article assesses the process of joint knowledge production (Hegger et al., 2014). The last article describes the approach, methods, and results of a multi-partner pilot project that was used to assess vulnerabilities of natural and built systems to climate change and develop adaptation options for inclusion in a climate change adaptation strategy (Lemieux et al., 2014). Overall, the process demonstrated the importance of engaging appropriate expertise and adopting a flexible and stakeholder-enabling adaptation framework. Considering the small number of identified articles, there is no main R&I actors.

Knowledge domain: Institutions & governance

- **Interest in the topic**

Sixteen articles (from 2011-2020) relating to climate change adaptation with a focus on “institutions & governance” exist on Scopus. More than 80 % of the existing articles on the topic (13/16) were published between 2016 and 2020.

- **Existing research & knowledge**

The articles examine different scales of governance towards climate change adaptation. The focus varied from the local level to national governance including multi-level governance. Seven articles investigate the challenges in mainstreaming climate change adaptation into land use plans. Among these articles, how local governments mainstream climate change adaptation into the local land use plans is developed through case studies in five articles. At another scale, two articles analyse the implementation of climate change adaptation strategies across multiple levels of governance by focusing on land use planning (Godden et al., 2011; Juhola et al., 2016). The articles highlight the barriers at the local level that emerge from the existing governance structures and cannot be solved by the local level alone. On another issue non-related to land use planning, four articles examine forms of multi-level governance that have been identified as key to climate change adaptation. Among these four articles, one article provides a framework for operationalizing the concepts of multi-level and collaborative governance to implement ecosystem-based adaptation (Ziervogel et al., 2017). Another article brings recommendations for further articles of governance and management alternatives, and for extending and strengthening state and local capabilities of coastal environmental processes within integrated coastal environmental management systems (Obraczka et al., 2017). On a higher level of governance, one article conducted a qualitative case study to explore how federal land managers approach adaptation (Timberlake et al., 2017). The role of institutional context in mediating the demand for information in the context of adaptation is analysed in another article (Archie et al., 2014). The integration of disaster risk reduction and climate change adaptation for regional governance is also studied (He et al., 2020).

- **Main actors publishing on the topic**

More than half of the published articles come from the United States and Australia. Within Europe, very little articles were published. One article was published in Sweden, one in Germany and another in Finland. There are no main institutions involved in the production of more than one article on the topic, except from the Australian National University (Australia) involved in two articles.

Knowledge domain: Specific regions

- **Interest in the topic**

35 articles (from 2008 - 2020) relating to climate change adaptation with a focus on “specific regions” and soil or land exist on Scopus. More than half of the existing articles on the topic (21/35, 60%) were published in the last five years (2016-2020).

- **Existing research & knowledge**

Among the 35 articles, eight, ten, nine and seven articles have a focus on respectively Mediterranean regions, mountain areas, urban areas and coastal areas.

Regarding Mediterranean regions, eight articles were published over the time period 2012 to 2020, of which four articles during the year 2020. These articles cover a range of topics. Soil carbon management for climate change adaptation is addressed in two articles. Three articles develop the impacts of climate change on reservoir water availability, quality and soil water balance in a water scarce Mediterranean region. Perspectives are suggested. Another article assesses 104 sustainable land management practices adopted within the Mediterranean Basin and documented in the World Overview of Conservation Approaches and Technologies global database (Ruiz et al., 2020). The article provides a Basin-wide integrated view that facilitates the coordination of sustainable management strategies across the Mediterranean region.

Among the ten articles concerning mountain area focus is set on (1) the effect of climate on mountain grassland production in relation with livestock herding practices; (2) policy, practice, and partnerships for climate change adaptation on forests; (3) mountain water resources with some recommendations for research, management and policy.

The nine articles related to urban area all explore urban heat island, influenced by sealed surfaces. The influence and relative importance of urban characteristics on remotely sensed land surface temperature, during both the day and night is developed in two articles. Furthermore, articles discuss climate change adaptation strategies for managing rising temperatures in large and rapidly warming metropolitan regions. Results shows that urban heat island management both within and beyond the central developed core of large cities provides an effective climate change adaptation strategy for large metropolitan regions. Three articles suggest using urban climate modelling and improved land use classifications to support climate change adaptation in urban environments.

All seven articles focusing on coastal areas and islands agree that governments and landowners in coastal areas need to plan for change, since they will particularly be affected by climate change. The articles review and make recommendations for changes in planning processes at the local and regional levels to prepare for the potential impacts of a changing climate. One specific article (Torresan et al., 2016) presents a tool to support decision making and climate proofing in a wide range of situations (e.g. shoreline planning, land use and water resource management, flood risk reduction). Another article presents an integrated spatial planning model for climate change adaptation in coastal zones (Ko et al., 2012).

- **Main actors publishing on the topic**

United States, Spain and United Kingdom are worldwide the main publishing countries. In the EU, beside from Spain and the United Kingdom, Netherlands and France are the countries who published the most articles. Spain is the country who published the most on the topic related to the Mediterranean rural region, whereas United States published the most on coastal areas / islands. The main publishing institution on the topic is the Consejo Superior de Investigaciones Cientificas (Spain) involved in the production of 5 articles, followed by the Colorado State University in the United States (3 articles). No authors published more than two articles on the topic.

Knowledge domain: Specific sectors & practices

Fifteen articles (from 2010 - 2020) relating to climate change adaptation with a focus on "specific sectors & practices" exist on Scopus. More than two thirds of the existing articles on the topic (11/15, 73%) were published between 2016 and 2020. The number of articles being published increased each year and reached 5 in 2020.

Sustainable land management practices are the main focus of the articles within the area of sectors and practices related to climate change adaptation. More than half of the published articles (9) relate to agroforestry and examine the gains accruing from agroforestry adoption to cope with climate change. More specifically, 4 articles develop the requirement for an agroforestry success as a climate change adaptation strategy in cocoa and coffee systems. The other 5 articles on agroforestry provide some recommendations and limitations from which decision-makers can select the most suitable arrangement for an agroforestry system to make it climate-resilient in order to be further adapted and scaled-up. The remaining articles (6) develop

each one specific sustainable land management practice such as soil tillage, legume intercropping, conservation agriculture, biochar, mixed cropped livestock systems and were published over the time period 2016 to 2020.
The main institution involved in the production of articles is World Agroforestry Centre (ICRAF) as most of the published articles have a focus on agroforestry. Aside from ICRAF, the other institution who produced more than 2 articles on the topic is Wageningen University & Research (Netherlands). ICRAF having its headquarters in Kenya, Kenya is the main publishing country followed by Australia and Colombia. In Europe, Germany, the Netherlands and Spain are the countries who published the most articles. No author published more than one article on the topic.

Knowledge domain: Basic knowledge production

There is a total of 101 articles not related to any knowledge domain and in relation to climate change adaptation. These are articles were published between 2008 and 2020. There was a significant increase in general attention in this area within the last years. 63 % of the existing articles on basic knowledge were published between 2016 and 2020. The number of articles being published increased each year and reached 20 in 2018. Aside from climate change adaptation, the main terms found in the articles are "land use", "soil organic carbon", "land management", "water conservation", "effects of climate change". The map of the articles' textual content is presented in Figure 41. The main terms used in the 101 articles are distributed in five clusters, 1: "land management", 2: "adaptation strategies", 3: "soil water", 4: "water conservation", 5: "soil frost". The clusters have many interconnectivities and no overlaps between them. All clusters interconnect with each cluster except from the cluster 5: "soil frost".
In Europe, Germany followed by the United Kingdom, the Netherlands and France are the countries who published the most articles. The main institution involved in Europe is Wageningen University & Research (Netherlands).

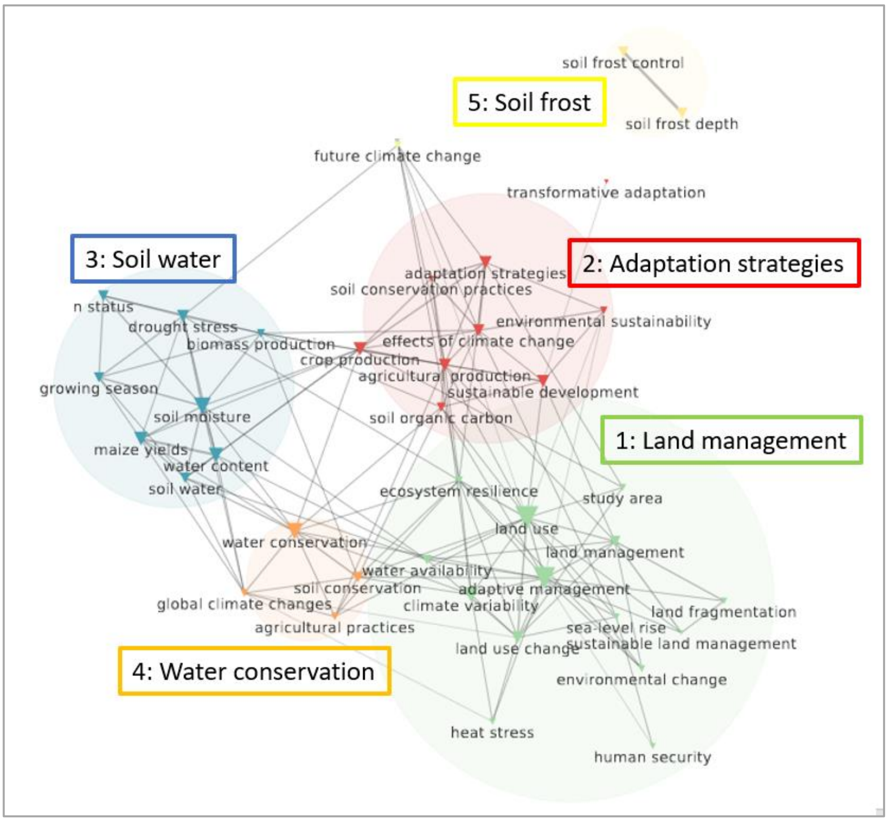


Figure 41: Cluster map of the main terms used in the full corpus (101 articles)

5. Societal challenge: reduce soil degradation

Knowledge domain: entire societal challenge

- **Interest in the topic**

11,285 scientific journal articles related to soil degradation reduction were identified. The articles were published between 1919 and 2020. There has been a significant increase in general attention in this area since 1992 (Figure 42). The number of articles being published reached 825 in 2020. 30 % of the existing articles on the topic (3309/11,285) were published in the last five years between 2016 and 2020.

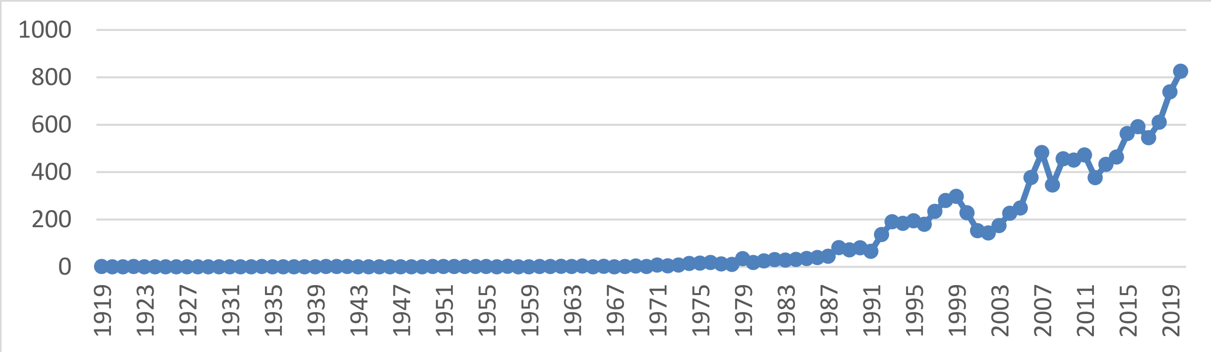


Figure 42: Chronologic number of articles published on the topic "reduce soil degradation"

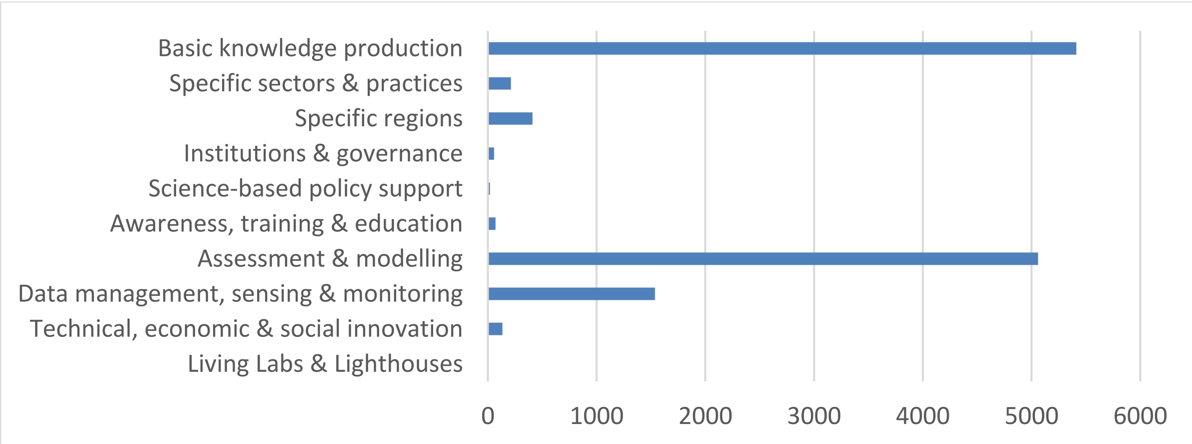


Figure 43: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 11,285 articles (Figure 43). One article can address several knowledge domains. About half of all articles (5061/11,285, 45 %) have a focus on the knowledge domain "assessment and modelling". The other knowledge domain which is substantially addressed is "data management, sensing & monitoring" with 14 % (1537/11,285) of all articles. At least 48 % of the articles are on basic knowledge production, not related to any particular knowledge domain (5413/11,285). Some research was conducted within "specific sectors & practices" (212) and "specific regions" (411). Less research was conducted within "science-based policy support", "institution & governance" and "Living Labs & Lighthouses".

- **Existing research & knowledge**

The full corpus was analyzed textually to review the themes addressed in the 11,285 articles. Overall, the main terms found in the articles are "soil pollution control", "soil erosion", "land use", "contaminated soil", "heavy metals", "water quality" and "soil loss". The map of the articles' textual content is presented in Figure 44. The main terms coalesce together in six clusters around the themes 1: "Soil pollution", 2: "Water pollution", 3: "Soil erosion" and 4: "Air pollution", 5: "Organic matter" and 6: "Risk assessment". The clusters 1 and 6 overlap. The closer the nodes are placed to each other on the map, the higher the frequency with which two terms occur in the same item. Therefore, risk assessment is often related to soil pollution.

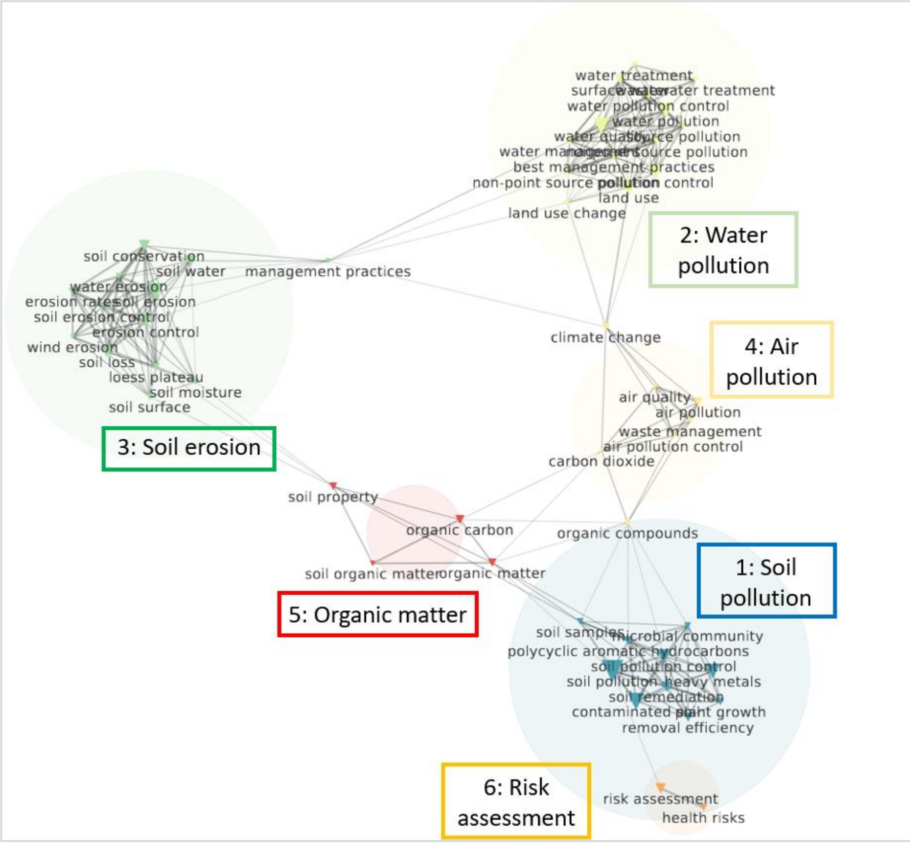


Figure 44: Overall cluster map of the main terms used in the full corpus (11,285 articles)

The Thematic Strategy for Soil Protection identifies the key soil threats in the EU as erosion, floods and landslides, loss of soil organic matter, salinization, contamination, compaction, sealing, and loss of soil biodiversity. The articles from the corpus focus on soil erosion, heavy metal accumulation, loss of organic matter. The other areas like compaction, sealing, floods and landslides are less addressed. There are also many studies on air pollution (industrial emissions) and the quality of water, a reason could be because of the Industrial Emissions Directive. The directive aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU. It provides an integrated approach to prevention and control of emissions into air, water and soil, to waste management, to energy efficiency and accident prevention, and as well ensuring that the operation of an installation does not lead to a deterioration of the quality of soil and groundwater.
In the context of the EU Soil Thematic Strategy and in parallel policy streams, a number of activities have been carried out by the EU for soil and land protection. Land and soil degradation are a global concern. For instance, land degradation neutrality is one of the targets of the UN Sustainable Development Goals (Agenda 2030). A UN Convention is dedicated to combat desertification (UNCCD) while the UNEP and FAO have dedicated activities on soil protection.

- **Main actors publishing on the topic**

A quarter of all articles (2860/11,285, 25 %) were carried out in China (Figure 45). A substantial proportion of the articles were also conducted in the United States (2533/11,285, 22 %). In Europe, United Kingdom followed by Germany and Spain are the countries who published the most articles (respectively 6 %, 4 % and 4 %). 12 European institutions were involved in the production of at least 40 distinct articles each on the topic (Figure 46). The main institutions involved in Europe are the Consejo Superior de Investigaciones Científicas (Spain) and Wageningen University & Research (Netherlands), with respectively 142 and 110 articles.

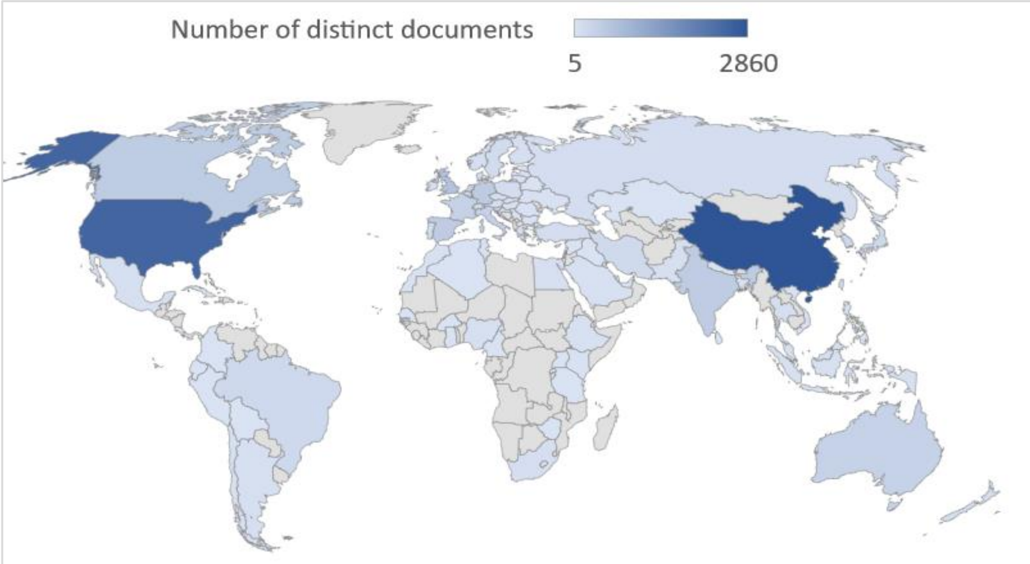


Figure 45: Map representation of the countries where at least 5 articles were published

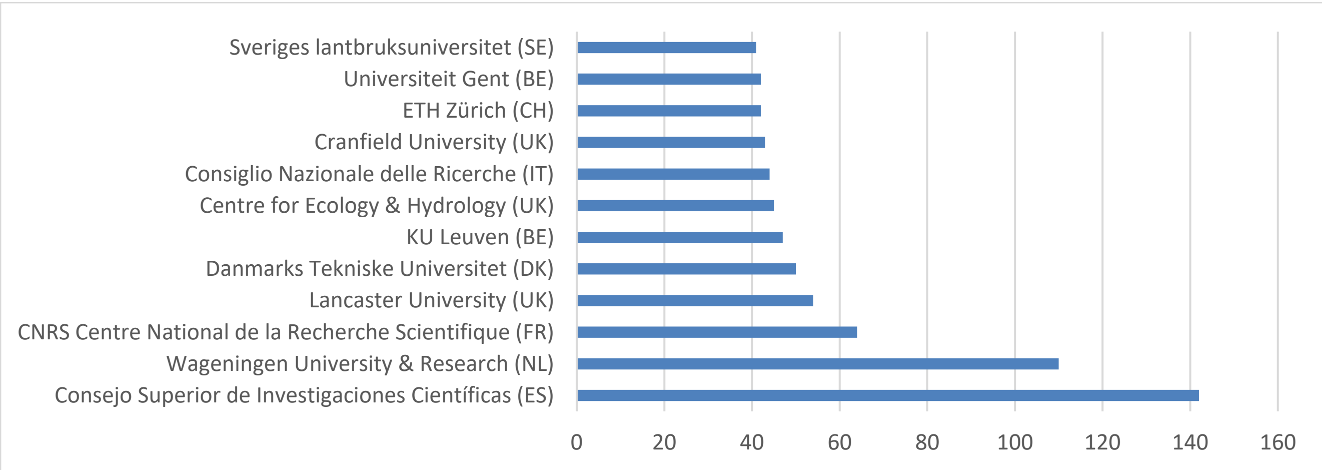


Figure 46: Main institutions in Europe who published more than 40 articles on the topic

There are 8 communities of authors (represented by clusters). The clusters have many interconnectivities and overlaps between them (Figure 47). Authors tend to publish in with various communities of authors. The authors who published the most on the topic are Wang, Y., Wang, X., Zhang, Y., Wang, J., Liu, Y. from China.

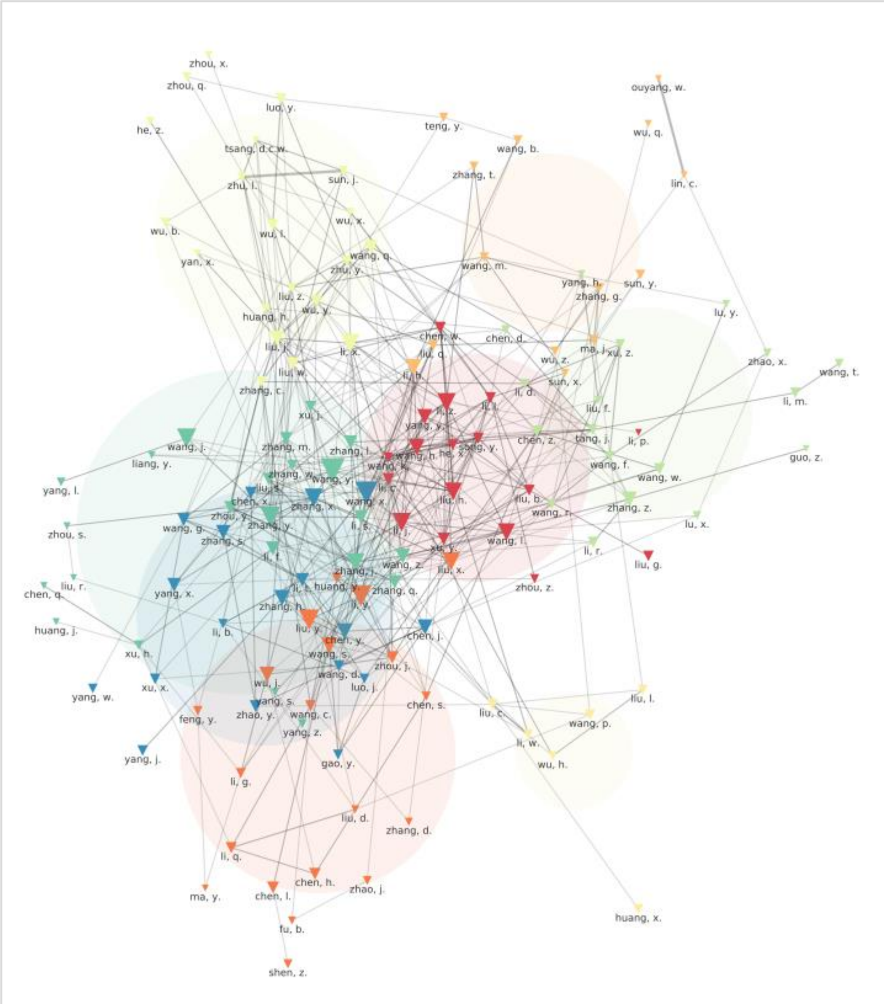


Figure 47: Map representing the interconnectivities between the main authors

<u>Knowledge domain: Living Labs & Lighthouses</u>

One article on “Living Labs & Lighthouses” was found (Yusoff et al., 2018) published by the University of Malaya in Malaysia. The article is a case study of the set up a Living Lab to spearhead the development of a sustainable waste management model.

<u>Knowledge domain: Technical economic & social innovation</u>

- **Interest in the topic**

There is a total of 133 articles on Scopus published between 1979 and 2020. There was a significant increase in general attention in this area since 2009. 27 % (36/133) of the existing articles on the topic were published between 2016 and 2020.

- **Existing research & knowledge**

The main terms found in the articles are in descending order “pollution control”, “management practices”, “erosion control” and “land use”. The map of the articles’ textual content is presented in Figure 48. The main terms used in the 133 articles are distributed in four clusters, 1: “Water pollution”, 2: “Soil erosion”, 3: “Air pollution”, 4: “Soil pollution”. No overlap between the clusters is observed. The main focus of the articles is the description of innovations to reduce soil erosion and the accumulation of heavy metals, hazardous waste in soil. Blais et al. (2010) reports new technologies for toxic metals removal from contaminated sites.

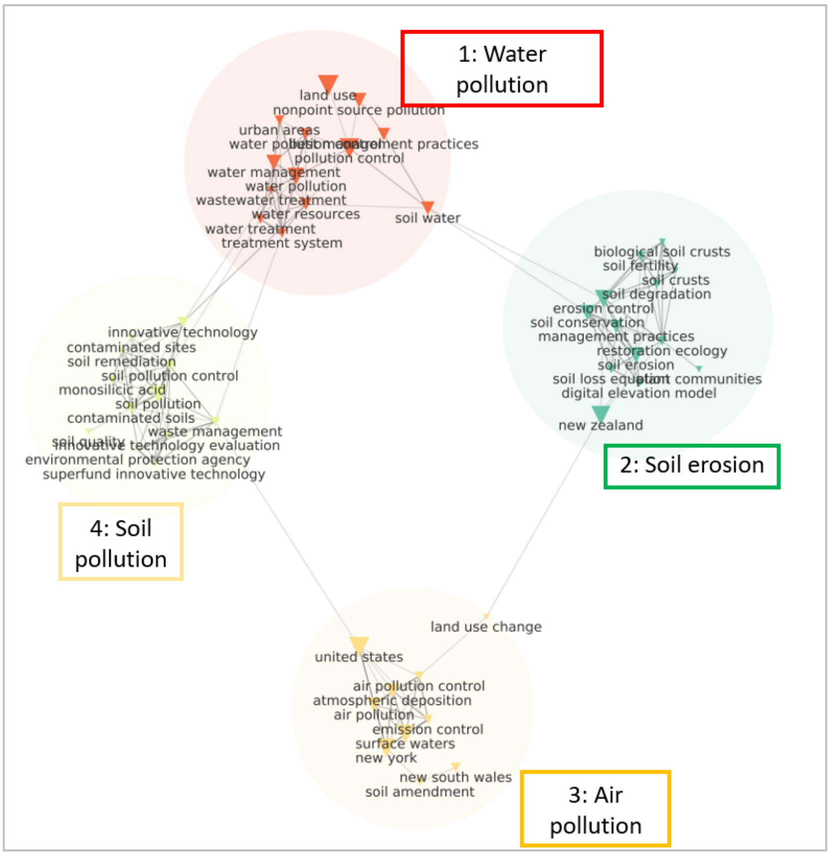


Figure 48: Cluster map of the main terms used in the full corpus (133 articles)

- **Main actors publishing on the topic**

Almost one third of all articles (42/133, 32 %) were carried out in the USA (Fig. 4). A substantial proportion of the articles were also conducted in New Zealand (21/133, 16 %). In Europe, France is the country who published the most articles (10 articles). The main European institution in Europe is INRAE – National Research Institute for Agriculture, Food and Environment (France), involved in 6 articles.

Knowledge domain: Data management, sensing & monitoring

- **Interest in the topic**

1,537 related scientific journal articles were identified. The articles were published between 1976 and 2020. 35 % of the existing articles (540/1,537) on the topic were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reaches 130 in 2020.

- **Existing research & knowledge**

The main terms found in the articles are in descending order “pollution control”, “land use”, “source pollution”, and “water quality”. The map of the articles’ textual content is presented in Figure 49. The main terms used in the 1537 articles are distributed in four clusters, 1: “Soil contamination”, 2: “Water pollution”, 3: “Air pollution”, 4: “Soil erosion”. The clusters 2 and 4 overlap. The main focus of the articles is related to the monitoring and data management of soil erosion and soil pollution. Few studies focus on soil compaction and desertification.

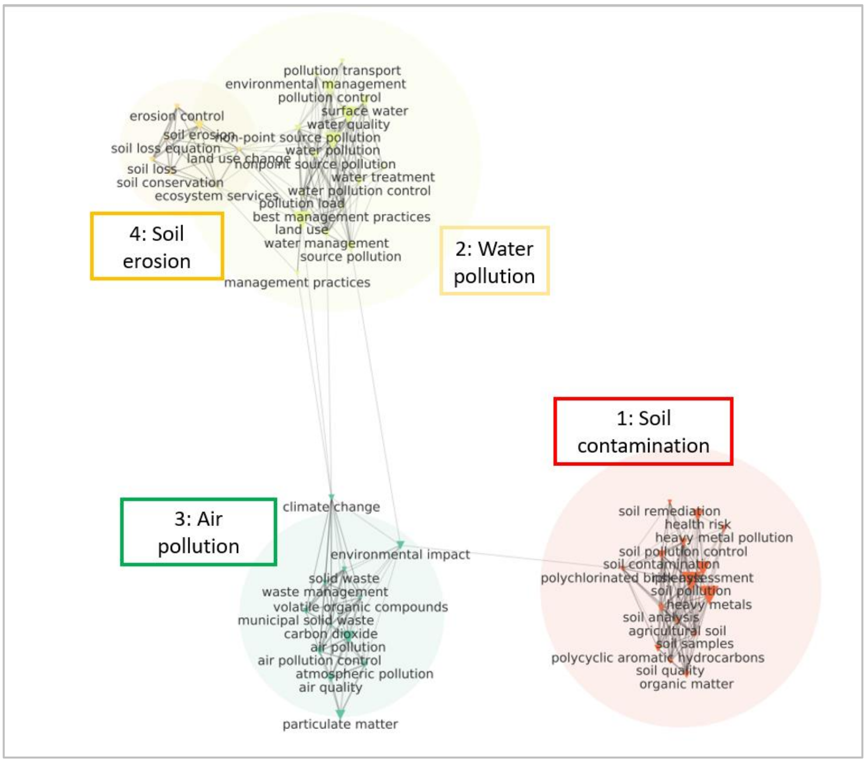


Figure 49: Cluster map of the main terms used in the full corpus (1,537 articles)

- **Main actors publishing on the topic**

Almost one third of all articles (458/1,537, 30 %) were carried out in China (Fig. 4). A substantial proportion of the articles were also conducted in the United States (325/1,537, 21 %). In Europe, the United Kingdom followed by France are the countries who published the most articles (respectively 8 % and 4 %). The main European institutions in Europe are the CNRS – Centre National de Recherche Scientifique (France), involved in 18 articles and Sveriges lantbruksuniversitet from Sweden (14 articles).

Knowledge domain: Assessment & modelling

- **Interest in the topic**

5,061 related scientific journal articles were identified. The articles were published between 1974 and 2020. 35 % of the existing articles (1,773/5,061) on the topic were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reaches 441 in 2020.

- **Existing research & knowledge**

The main terms found in the articles are in descending order “pollution control”, “soil pollution”, “land use”, “source pollution”, “soil erosion” and “water pollution”. The map of the articles’ textual content is presented in Figure 50. The main terms used in the 5,413 articles are distributed in six clusters, 1: “soil pollution”, 2: “water pollution”, 3: “land use change”, 4: “air pollution”, 5: “risk assessment” and 6: “soil organic matter”. The main focus of the articles is related to the assessment and modelling on soil erosion and soil pollution. Few studies focus on soil compaction and desertification.

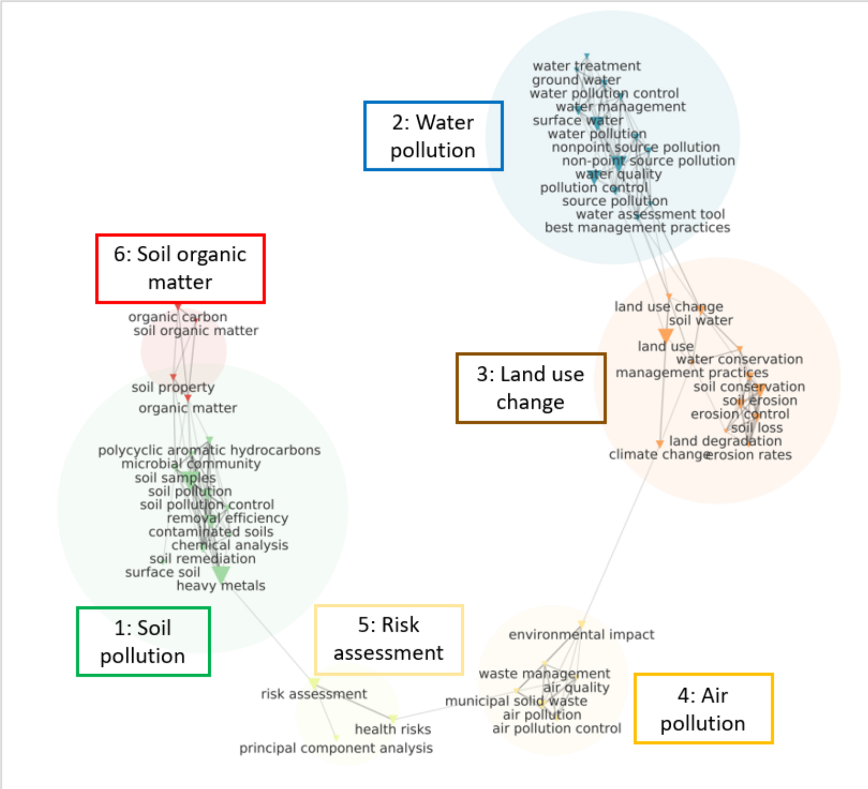


Figure 50: Cluster map of the main terms used in the full corpus (5,061 articles)

- **Main actors publishing on the topic**

Almost one third of all articles (1,464/5,061, 29 %) were carried out in China (Fig. 4). A substantial proportion of the articles were also conducted in the United States (1,178/5,061, 23 %). In Europe, the United Kingdom followed by Spain and France are the countries who published the most articles (respectively 6 %, 5 % and 4 %). The main European institutions in Europe are Consejo Superior de Investigaciones Científicas (Spain), involved in 57 articles and Wageningen University & Research from the Netherlands (52 articles).

Knowledge domain: Awareness, training & education

70 related scientific journal articles were identified. The articles were published between 1983 and 2020. 33 % of the existing articles (23/70) on the topic were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reaches 8 in 2020. The main terms coalesce together in six clusters. Clusters are centred on pollution control, water pollution, erosion control, flow slides, control measures, decision support. Most of the articles focus on pollution control, water and erosion control. However, the other degradation types (desertification, salinization, acidification) are less covered in the articles. Throughout the years, change in the topics of research can been seen. In the 1970s, concerns were mostly on health education nowadays in 2020, most articles focus on heavy metals and metal pollutions.
One quarter of all articles (18/70, 26 %) were carried out in the United States (Fig. 4). A substantial proportion of the articles were also conducted in China (11/70, 16 %). In Europe, Belgium is the country who published the most articles (6 %). The main European institutions in Europe is the Universiteit Gent (Belgium), involved in 4 articles.

Knowledge domain: Science-based policy support

19 articles were found on Scopus (from 1971 to 2019) relating to science-based policy support. A quarter of all the articles were published in the last five years (2016-2020). Among the 19 articles, five articles are related to soil erosion, four to desertification and two to contamination. Salinization, acidification and compaction are lacking topics. The other articles do not focus on a specific degradation type. Most articles are not case studies, they give a comprehensive summary for a given challenge to support policies design by assisting policymakers to better appreciate implications. United States published the most paper and only seven articles were published by EU member states (mostly from the Netherlands).

Knowledge domain: Institution & governance

57 related scientific journal articles were identified. The articles were published between 1990 and 2020. 40 % of the existing articles (23/57) on the topic were published in the last five years between 2016 and 2020. Pollution control is the term that occurs the most in all articles. Throughout the years, change in the topic of research can be seen. In the 1990s, concerns were mostly on land use, whereas nowadays in 2020, most articles focus on water pollution control, as the excess use of fertilizers in the past decades has resulted in serious environmental issues worldwide. Several global and EU strategies have aimed to mitigate water pollution from agricultural sources in the future.

A substantial proportion of the articles were conducted in China (17/57, 30 %). In Europe, the United Kingdom, Italy and France are the countries who published the most articles (evenly 7 %).

Knowledge domain: Specific regions

411 related scientific journal articles were identified. The articles were published between 1971 and 2020. 33 % of the existing articles (136/411) on the topic were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reaches 30 in 2020.

Soil loss is the term that occurs the most in all articles. The main terms used in the 411 articles are distributed in six clusters: soil loss, soil organic matter, pollution control, water quality, climate change and land use change. Some topics are not well covered such as salinization, acidification, desertification. 118 articles are focusing on Mediterranean area, 99 articles on mountains regions, 9 on boreal and oceanic regions, 21 on deserts, 16 on karst area, 9 on tropical area, 2 on polar region, 24 on wetlands and 25 on urban area.

17 % of all articles (71/411) were carried out in Spain (Fig. 4). A substantial proportion of the articles were also conducted in China (64/411, 16 %). In Europe, apart from Spain, Italy followed by France are the countries who published the most articles (respectively 10 % and 8 %). The main European institutions in Europe are Consejo Superior de Investigaciones Científicas (Spain), involved in 32 articles and the University of Valencia from Spain (14 articles).

Knowledge domain: Specific sectors and practices

212 related scientific journal articles were identified. The articles were published between 1986 and 2020. 35 % of the existing articles (74/212) on the topic were published in the last five years between 2016 and 2020. The number of articles being published reached 16 in 2020.

The majority of the articles relate to agroforestry, 36 articles focus on vineyards, 56 on orchards and 40 on intercrops. The topic of soil contamination is well covered: 38 soil contamination related articles were found on Scopus in the field of "specific sectors & practices". Erosion control is also well covered in the articles. However, some degradation processes are not studied in depth. Desertification, salinization, compaction occur only in a few papers.

Almost one third of all articles (51/212, 24 %) were carried out in China (Fig. 4). A substantial proportion of the articles were also conducted in the United States (37/212, 17 %). In Europe, Spain followed by Germany are the countries who published the most articles (respectively 16 % and 12 %). The main European institutions in Europe are Consejo Superior de Investigaciones Científicas (Spain), involved in 11 articles and the University of Valencia from Spain (8 articles).

Knowledge domain: Basic knowledge production

There is a total of 5,413 articles on basic knowledge production, not related to any knowledge domain and in relation to soil degradation reduction. These are articles were published between 1919 and 2020. There was a significant increase in general attention in this area within the last years. 25 % of the existing articles on basic knowledge were published in the last five years between 2016 and 2020. The number of articles being published increased each year and reached 323 in 2020.

The main terms found in the articles are "pollution control", "soil pollution", "soil erosion", "contaminated soil" and "heavy metals". The map of the articles' textual content is presented in Figure 51. The main terms used in the 5,413 articles are distributed in four clusters, 1: "soil erosion", 2: "contaminated soil", 3: "land use" and 4: "water pollution". All clusters interconnect only with cluster 3: "land use".

In Europe, Germany followed by the United Kingdom, Spain and France are the countries who published the most articles. The main institution involved in Europe is Wageningen University & Research (Netherlands).

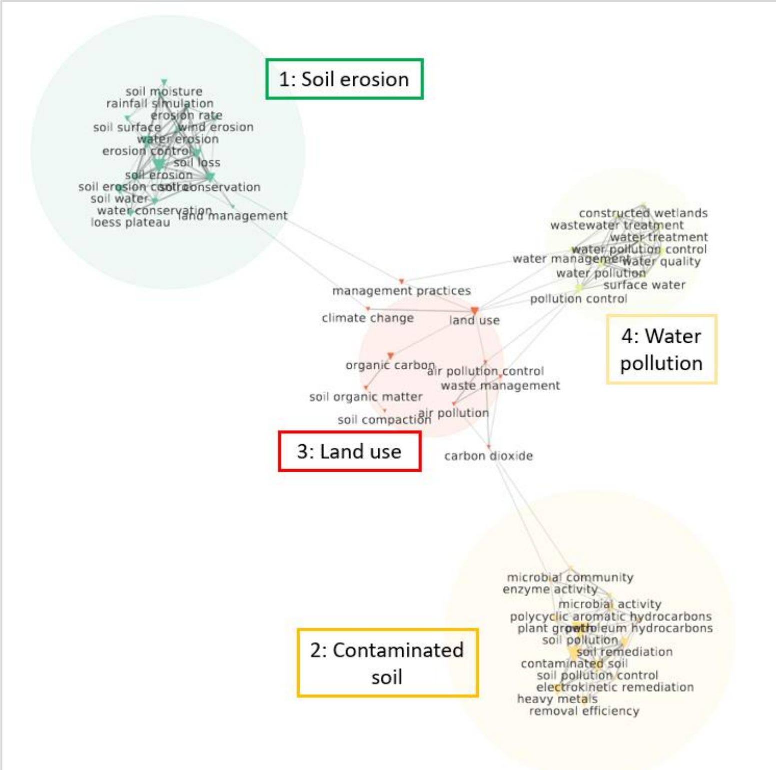


Figure 51: Cluster map of the main terms used in the full corpus (5,413 articles)

6. Societal challenge: increase biodiversity

Knowledge domain: entire societal challenge

- **Interest in the topic**

130 academic articles related to biodiversity increase were identified. The 130 articles were published between 1983 and 2020 (Figure 52). About half of the existing articles on the topic (57/130, 44 %) were published in the last five years (2016-2020). The number of articles being published reaches 15 in 2020.
Biodiversity is an area of growing interest from 2013 not only for the scientific community but globally due to the international and European commitments in this matter (2030 Agenda for Sustainable Development, European Green Deal, and the new EU Biodiversity Strategy for 2030). Loss of biodiversity is not only an environmental issue, but also a developmental, economical, security, health, social and ethical issue. This is illustrated by the Global Risks Report 2020 that identifies biodiversity loss and ecosystem collapse within the top five major threats that may impact global prosperity in 2020 and over the next decade.

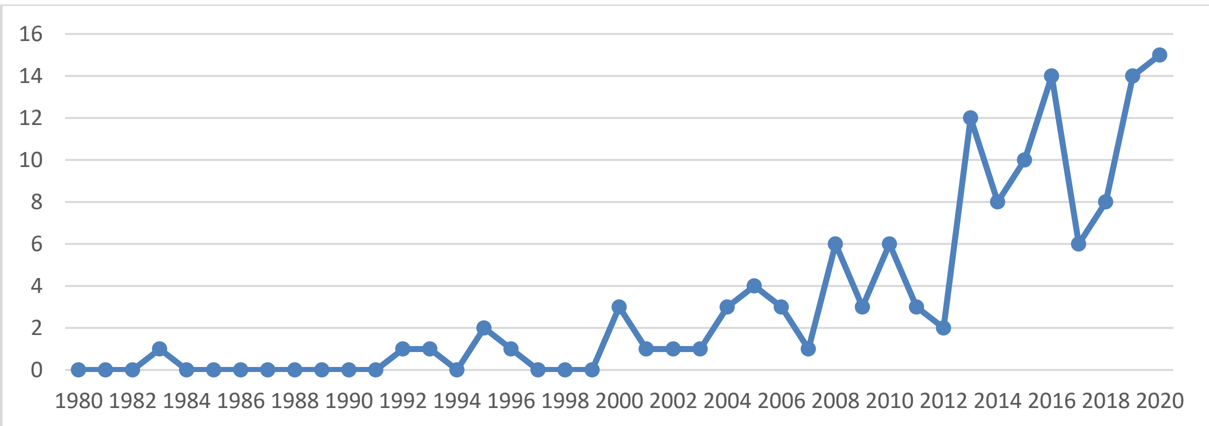


Figure 52: Chronologic number of articles since 1980 published on “increase biodiversity”

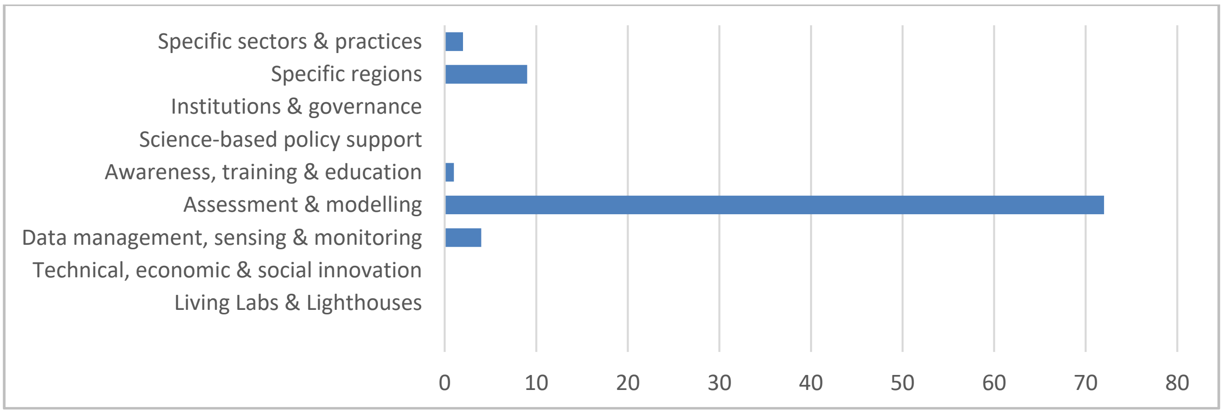


Figure 53: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 130 articles (Figure 53). One article can address several knowledge domains. More than half of all articles (72/130, 55 %) have a focus on the knowledge domain “assessment and modelling”. The other knowledge domain which is substantially addressed is “specific regions” with 7 % (9/130) of all articles. At least 52 articles are basic knowledge production, not related to any particular knowledge domain (52/130, 40 %). No research was conducted within “science-based policy support”, “Living Labs & Lighthouses”, “institutions & governance” and “technical, economic & social innovation”.

- **Existing research & knowledge**

The full corpus was analysed textually using CorTexT to review the themes addressed in the 130 academic articles. Overall, the main terms found in the articles are “life cycle”, “impact assessment”, “biodiversity conservation”, “soil biota” and “land-use change”. From 2000 to 2020, the main terms used in articles have not varied demonstrating of a similar focus throughout time. However, new terms have appeared in the last years such as “nematode communities”. The map of the articles’ textual content is presented in Figure 54. The main terms used in the 130 articles are distributed in four clusters 1: “environmental impact assessment”, 2: “soil biota”, 3: “soil biodiversity”, 4: “biodiversity conservation”. The clusters have very few interconnectivities and no overlaps between them.

During the 90s, there were several methods commonly used and well-established for impact assessment on biodiversity, Geographic information systems (GIS) - based methods, and Life Cycle Assessment (LCA) methods, but there was a need to include all complex aspects related to land use and land use change and ecosystem services. This gap was addressed in the UNEP-SETAC (United Nations Environment Program/Society of Environmental Toxicology and Chemistry) guideline on global land use impact assessment on biodiversity and ecosystem services in LCA (2013) (adapted in 2016 according to experts’ recommendations). This document was considered as a highlight in this research area. Regarding awareness, training and education, there is only an article about landowners´ attitude towards biodiversity conservation in Poland, concluding that the use of a regulatory approach can have an influence. Another article published outside Scopus within this topic, titled: “Challenges of Biodiversity Education: A Review of Education Strategies for Biodiversity Education”, published in 2012 by Cornell University (USA), identified four main challenges: the need to define an approach for biodiversity education, biodiversity as an ill-defined concept, appropriate communication, and the disconnection between people and nature.

The EU has many instruments as well as an extensive legal and policy framework aimed to protect, restore, and sustainably manage its natural habitats, species, and ecosystems. However, according to the State of Nature in the EU Report (2020), only 16% of the most important natural habitats and 23% of the protected species are doing well, indicating unsatisfactory status of biodiversity in Europe. Facing the current biodiversity crisis and its multiple drivers, the reinforcement of science-based knowledge on biodiversity status, dynamics and trends, and on the multiple and interacting causes and consequences of biodiversity loss and degradation of ecosystem services is needed as on levers of action. Moreover, research is also needed to develop and assess novel tools and approaches to biodiversity conservation, restoration, and sustainable management, including Nature-based Solutions; to develop guidelines to promote 'closer to nature' standards and practices across different sectors; and to underpin the ability to measure and communicate progress towards the upcoming targets of policy agendas. It is also important to support academically excellent research that is the basis to inform and support policy makers and other stakeholders.

Biodiversity is one of the eight indicators on soil health as noted in the Interim report of the Mission Board for Soil health and food "Caring for Soil is Caring for Life" (2020), therefore innovative proximal and remote sensing and monitoring techniques should be further developed to allow rapid and accurate measurements for efficient soil health monitoring.

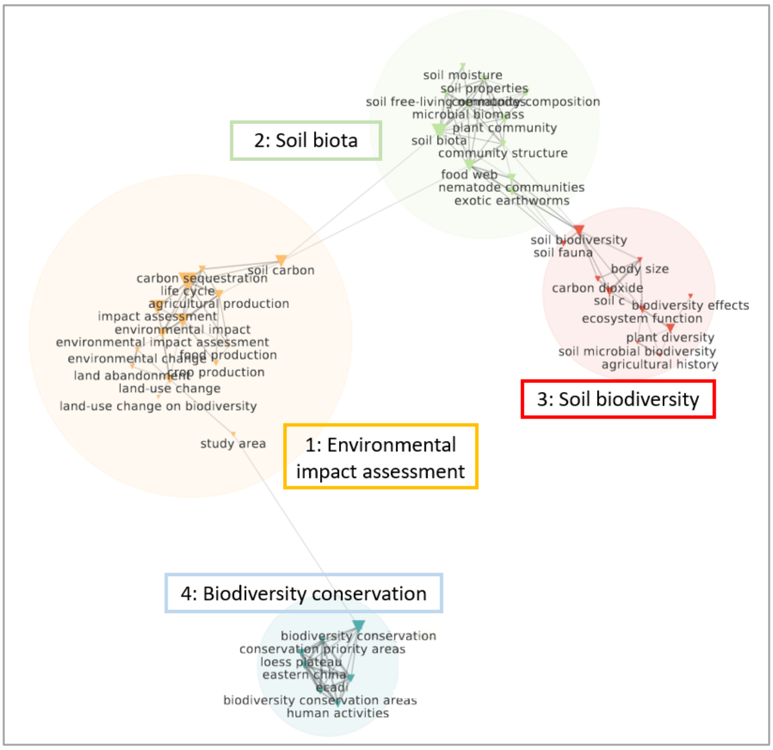


Figure 54: Overall map of the main terms used in the full corpus (130 articles)

- **Main actors publishing on the topic**

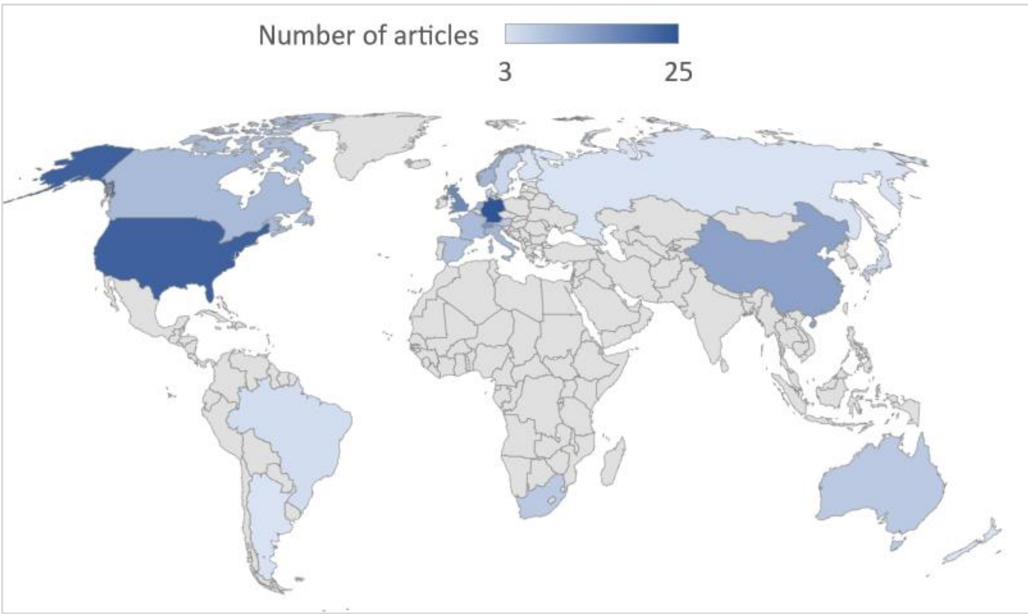


Figure 55: Map representation of the countries where at least 3 articles were published

Germany is the country which published the highest number of articles (Figure 55). A substantial proportion of the articles were also conducted in the United States (23/130, 18%). In Europe, aside from Germany, the United Kingdom and Switzerland are the countries who published the most articles (respectively 19%, 13% and 12%). Four European institutions were involved in the production of at least 5 distinct articles on the topic (Figure 56). The main institutions involved in Europe are ETH Zürich (Switzerland) and Norges teknisk-naturvitenskapelige universitet (Norway), with respectively 10 and 9 articles.

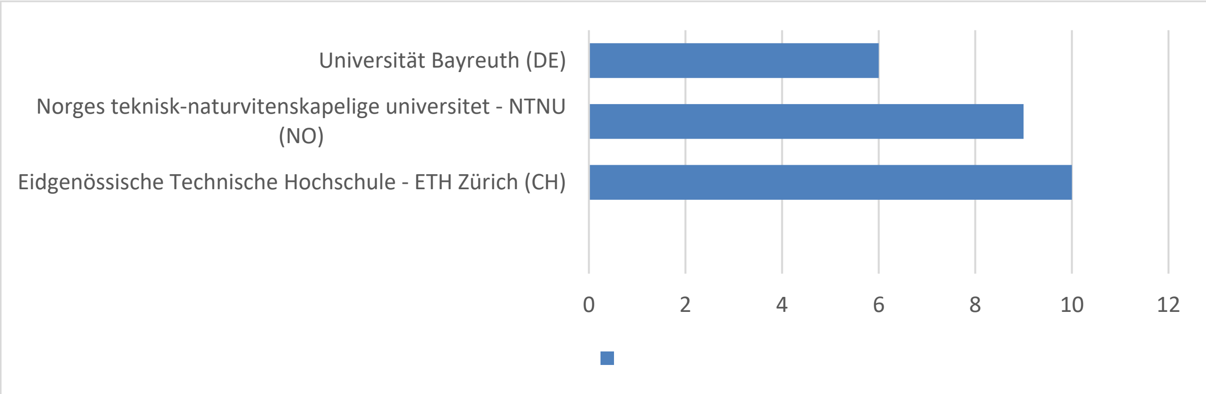


Figure 56: Main institutions in Europe who published more than 5 articles on the topic

Authors tend to publish in small communities of authors with scarce interactions between the different communities of authors. Koellner T. (Universität Bayreuth, Germany) and Michelsen O. (Norges teknisk-naturvitenskapelige universitet, Norway) are the main authors in number of publications (respectively 6 publications each), but there are many authors with one to four publications. Koellner T. from University of Bayreuth publishes with various community of authors due to his contribution in UNEP/SETAC Life Cycle Initiative, participation in the project LULCIA, and affiliation to the University of Bayreuth, Professorship of Ecological Services, one of the most relevant research institutions in this area.

Knowledge domain: Living Labs & Lighthouses

No articles were found. There is no existing knowledge regarding "Living Labs & Lighthouses" related to biodiversity increase.

Knowledge domain: Technical, social & economical innovation

No articles were found. There is no existing knowledge regarding "Technical, economic & social innovation" related to biodiversity increase.

Knowledge domain: Data management, sensing & monitoring

Four articles relating to biodiversity increase with a focus on "data management, sensing & monitoring" exist on Scopus. The articles were published between 2013 and 2019. The main focus of articles within this area involves using remote sensing and monitoring to increase biodiversity in very diverse ways. The articles explore monitoring processes through case studies. The focus of the articles goes from the effect of local contamination to the effect of land use on wildlife, or the effect of consumer choices and food consumption both domestically and globally on water use and biodiversity or furthermore the impacts of land-based mining activities on marine ecosystems. The four papers cover several areas of research, but there are so many diverse areas. Spain is the country that published the most on the topic. Considering the few articles on the topic, there is no emerging main R&I actors.

Knowledge domain: Assessment & modelling

- **Interest in the topic**

The total number of articles published for the whole period (1992-2020) were 72. Until 2013, the number of articles published per year was 1 to 3. From 2013 this number increased, with 7 to 9 articles per year. We can consider two time periods: from 1992 to 2010 in which life cycle & crop production were the main concern, and from 2010 to 2020 in which ecosystems function, soil properties and environmental issues increased progressively.

This increase in the number of articles could be due partially to the UNEP/SETAC Guidelines publication, but mainly to the growing interest in the effects of climate change and environmental issues on the biodiversity. At global level, the Strategic Plan for Biodiversity 2011–2020 released by the Parties to the Convention on Biological Diversity of the United Nations was not only a commitment for the countries but a research area of growing interest for the scientific community. In addition, the Sustainable Development Goal 15 of the 2030 Agenda for Sustainable Development is devoted to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". At a European level, the European Green Deal and the new EU Biodiversity Strategy for 2030 are in line with these objectives.

- **Existing research & knowledge**

The main terms used in the 72 articles are "life cycle" and "impact assessment", followed by "plant species", "biodiversity conservation" and "land-use change". Besides Geographic information systems (GIS) - based methods, Life Cycle Assessment (LCA) methods were commonly used but there was a need to include all complex aspects related to land use and land use change. Whereas research on impacts of land use on biodiversity was a well-established field, research on ecosystem services was less developed. This gap was addressed in the UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA (2013) (adapted in 2016 according to experts' recommendations). After a long process of consensus building on framing the methodology, the UNEP-SETAC Life Cycle Initiative achieved a method to assess the use of land anywhere on the globe and developed a set of characterization factors that allows linking spatially explicit land use elementary flows of occupation and transformation to impacts on biodiversity and services provided by terrestrial ecosystems.

- **Main actors publishing on the topic**

One third of all articles (25/72, 35 %) were carried out in Germany (Fig. 4). A substantial proportion of the articles were also conducted in the United States (23/75, 32 %). In Europe, aside from Germany, the United Kingdom followed by Switzerland and Italy are the countries who published the most articles (respectively 24 %, 21 % and 14 %). 3 European institutions were involved in the production of at least 6 distinct articles each on the topic. The main institutions involved in Europe are ETH Zürich (Switzerland), Norwegian University of Science and Technology (Norway) and the University of Bayreuth (Germany), with respectively 8, 8 and 6 articles. Koellner (University of Bayreuth, Germany), Michelsen (Norwegian University of Science and Technology, Norway) and De Baan (ETH Zurich, Switzerland) are the main authors in number of publications (6, 5, 4 respectively).

<u>Knowledge domain: Awareness, training & education</u>

Only one article relating to "awareness, training & education" with a focus on increase biodiversity was found on Scopus. The article was published in 2015 and focusses on the factors affecting landowners´ attitude towards biodiversity conservation in Poland (Kamal et al., 2015).
Another article published outside Scopus within this topic, titled: "Challenges of Biodiversity Education: A Review of Education Strategies for Biodiversity Education", published in 2012 by Cornell University (USA), identified four main challenges: the need to define an approach for biodiversity education, biodiversity as an ill-defined concept, appropriate communication, and the disconnection between people and nature.

<u>Knowledge domain: Science-based policy support</u>

No articles were found. There is no existing knowledge regarding "Science-based policy support" related to biodiversity increase.

<u>Knowledge domain: Institution & governance</u>

No articles were found. There is no existing knowledge regarding "Institution & governance" related to biodiversity increase.

<u>Knowledge domain: Specific regions</u>

Nine articles (from 2005-2019) relating to biodiversity with a focus on "specific regions" exist on Scopus. Two thirds of the existing articles on the topic were published in the last years, between 2016 and 2019.

Some of the most common keywords are: biodiversity, ecosystem, conservation, land use, Mediterranean, bird, species richness, environmental change, or nematode. The 9 articles assess the effects of different parameters (intensity of use, grazing, land abandonment, environmental change, dike age, or avifauna) in different regions of the Mediterranean (6) or in a poplar forest in China in one case, or even the effects of history, urbanization and management in a Mediterranean urban park in Naples. Two articles take a rather different approach: the first one uses a model to predict the potential establishment of invasive plant species within protected areas of the Ukranian Carpathians in two future change scenarios: climate warming and anthropogenic disturbances in 2050 and 2100 (Simpson et al., 2013). The second article provides a method to estimate land market value in support of biodiversity conservation strategies (Fois et al., 2019).
As the main region of interest for this topic is the Mediterranean area, Spain and Italy are worldwide the countries who published most in this topic (3), closely followed by France, Israel and China (2). The institutions differ from one article to another.

Knowledge domain: Specific sectors & practices

Two articles (from 2007 and 2013) relating to "specific sectors & practices" with a focus on increase biodiversity exist on Scopus. One of the articles (De Baan et al., 2013) analyses the differences across land use types, biogeographic regions, species groups and data source in different world regions. An overall negative land use impact was found but results varied considerably, and the authors indicate that knowledge gaps on cause effect chains remain. The approach taken in the study allows a first rough quantification of land use impact on biodiversity in life cycle assessment although they are not intended to directly support decision-making on land management practices, fur such purpose more detailed and site-dependent articles are needed. The second article (de Koning et al., 2007) analysis the effects of different payments on biodiversity conservation in western Ecuador. The authors used a model that they conclude is a versatile tool to support planning of payments for conserving ecosystems. The two articles cover two different areas of research, and we may conclude that there are certainly knowledge gaps on specific sectors and practices.

Knowledge domain: Basic knowledge production

There is a total of 52 articles on basic knowledge production not related to any knowledge domain and in relation to biodiversity increase. These are articles were published between 1993 and 2020. 37 % of the existing articles on the topic were published between 2016 and 2020.
Aside from climate change adaptation, the main terms found in the articles are "soil biota", "climate change", "food webs", "soil biodiversity", "species composition".
In Europe, the United Kingdom followed by Germany and Switzerland are the countries who published the most articles (respectively 7, 5 and 4). No European institution published more than 2 articles on the subject.

7. Societal challenge: increase ecosystem services

Knowledge domain: entire societal challenge

- **Interest in the topic**

45 scientific journal articles related to increase of ecosystem services were identified. Articles were published between 2010 and 2020 (Figure 57). 69% of the existing articles on the topic (31/45) were published in the last five years between 2016 and 2020.

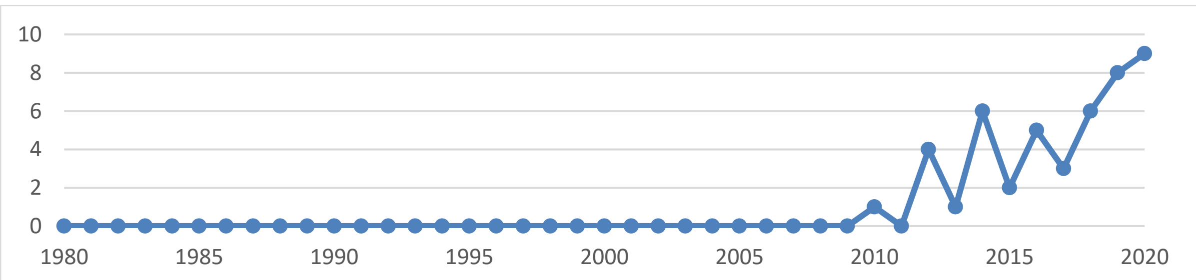


Figure 57: Chronologic number of articles published since 1980 on "increase ecosystem services"

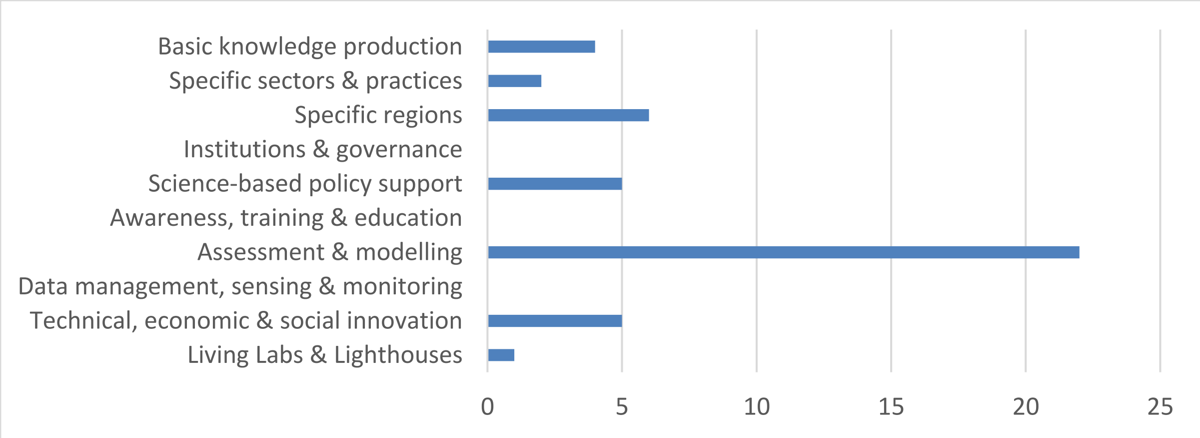


Figure 58: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the articles (Figure 58). Half of all articles (22/45) have a focus on the knowledge domain “assessment & modelling”. Other knowledge domains addressed are “Specific regions”, “Specific sectors & practices”, “Science-based policy support” and “Technical, economic & social innovation”. One article addresses “Living Labs & Lighthouses”. No research was found on “Institutions & Governance”, “Awareness, training & education” and “Data management, sensing & Monitoring”. Moreover 4 articles are “basic knowledge production”, not related to any particular knowledge domain. As there are less than 50 articles, no analysis with CorTexT was done.

- **Existing research & knowledge**

Main ecosystem services investigated are related to provision (biomass production) or regulation (e.g. carbon sequestration, regulation of water fluxes of quality) services. One paper was found dealing with cultural services. Habitat provision for wildlife is also covered by few papers.
In the literature, ecosystem services are not really measured nor monitored: all identified papers usually use model approaches to assess ecosystem services based on several sources of data as remote sensing image, land use occupations, reference/generic values (e.g. for carbon stocks). Using scenarios (e.g. changes in land use, in agricultural practices, in land cover), several calculations and maps of ecosystems services are produced. Such simulation can help in optimizing a service or a bundle of services.
Main developments were made in agricultural land use but forests and natural land uses are also investigated, as well as cities / peri-urban areas. Concerning agriculture, different systems (e.g. agroforestry, tillage/no tillage) and/or practices (e.g. cover crops, organic amendments) are compared and resulting ecosystem services such as biomass/food production, carbon storage, erosion prevention, water purification are assessed. This may help in selecting best practices and/or for designing systems that optimize certain ecosystem services.
It was underlined by several authors that the concept of ecosystem services is easy to communicate and can help the dialogue between actors. It is suggested that such assessments can support local and national policies by providing relevant information to come to a decision having in mind all possible trade-offs.
Main investigated specific regions are Mediterranean regions and mountains. Several studies, conducted by European institutions also deal with African situations to support trade-offs between natural preservation and agricultural/urban developments. China is also publishing mainly on the links between urban development, land planning and restauration/reservation of ecosystem services. A Living Lab was identified in Spain where urban and peri urban agriculture are at the core of different societal issues.

- **Main actors publishing on the topic**

Mainly European research organizations can be observed (Germany, Netherlands, Italy, Portugal). China and Australia also published in this field of research.

Knowledge domain: Living Labs & Lighthouses

Only one article was identified. The article was published by García-Llorente et al. in 2019. The paper describes the use of a participatory farming lab as a space to reactivate the agrarian sector in rural and peri urban areas of Madrid (Spain). Through interviews authors identified the most socially valued ecosystem services and the actions collectively taken to enhance them. Those ecosystem services are collectively managed and improved at the farm level through actions such as cultivating deep-root plants (artichokes for example) to provide soil structure, growing green manure as a soil amendment to fix nitrogen, creating nesting sites and field margins to provide suitable habitat for wild pollinators or soil mulching with straw to reduce water evapotranspiration and increase soil moisture.

Knowledge domain: Technical, social & economical innovation

Five articles were identified testing various technical innovations from landscape level (Segre et al., 2019; Blanco-Velazquez et al., 2019) to field (Williams et al., 2016) and laboratory (Burges et al., 2016). Macintosh et al. (2019) discussed how the management of phosphorus fertility may support several ecosystem services in agriculture. Segre et al. (2019) compared in a multi-taxa and landscape approach the cost-effectiveness of uncultivated field margins and semi-natural patches in Mediterranean areas.

Williams et al. (2016) described an innovation called "soil functional zone management (SFZM)". This novel strategy aims at developing sustainable production systems that attempt to integrate the benefits of conventional, intensive agriculture with no-tillage. SFZM creates distinct functional zones within crop row and inter-row spaces. By incorporating decimetre-scale spatial and temporal heterogeneity, SFZM attempts to foster greater soil biodiversity and integrate complementary soil processes at the sub-field level. Such integration maximizes soil services by creating zones of 'active turnover', optimized for crop growth and yield (provisioning services); and adjacent zones of 'soil building', that promote soil structure development, carbon storage, and moisture regulation (regulating and supporting services). These zones allow SFZM to secure existing agricultural productivity while avoiding or minimizing trade-offs with soil ecosystem services. Through the creation of functionally distinct but interacting zones, SFZM may provide a vehicle for optimizing the delivery of multiple goods and services in agricultural systems, allowing sustainable temporal intensification while protecting and enhancing soil functioning.

Burges et al. (2016) and Blanco-Velazquez et al. (2019) described strategies and approaches including phytotechnologies (phytostabilization or phytoremediation) to deal with contaminated land by trace elements from mining activities. The main aim is to promote the use of plants and trees to improve soil status and therefore ecosystem services provided by soils such as carbon storage, nutrient cycling, water flow regulation and purification.

Macintosh et al. (2019) argued that there is no operational framework in place to manage phosphorus fertility for multiple ecosystem services (ES) delivery. Furthermore, the costs of potentially sacrificing crop yield and/or quality were not yet identified. They analysed how the management of phosphorus fertility may support several ecosystem services in agriculture. They proposed that soil test phosphorus concentration provides a suitable common unit of measure by which delivering multiple ES can be economically valued relative to maximum potential yield. This value can then be traded, or payments made against one another, at spatio-temporal scales relevant for farmer and national policy objectives. Implementation of this framework into current phosphorus fertility management strategies would allow for the integration and interaction of different stakeholder interests in ES delivery on-farm and in the wider landscape.

Knowledge domain: Data management, sensing & monitoring

No article was found dedicated only to data collection/management, sensing and monitoring ecosystem services. In the literature, ecosystem services are not really measured nor monitored: all identified papers usually use model approaches to assess ecosystem services based on several sources of data as remote sensing image, land use occupations, reference/generic values (e.g. for carbon stocks). This is described in the next part dedicated to "Assessment and Modelling".

Knowledge domain: Assessment & modelling

- **Interest in the topic**

There is a total of 22 articles published between 2010 and 2020 on the topic. Ten paper concentrate on the development of methods to assess the following ecosystem services: soil erosion regulation (Rendon et al.,

2020, Steinhoff-Knopp and Burkhard, 2018, Kauffman et al., 2014), filtration of contaminants by soil (Makovnikova et al., 2019), carbon storage (Brady et al., 2015, Protirio et al., 2010), water regulation (McDonough et al., 2020), biodiversity habitat (Brady et al., 2015). Ma et al. (2021) and Gatto et al. (2019) developed method to assess different ecosystem services as provisional (e.g. timber or wood products), cultural (recreation or amenity) and regulation services (e.g. regulation of climate, water conservation, carbon sequestration, soil erosion control).
Methods developed for quantifying ecosystem service use remote-sensing data and/or geographical information system software. Several approaches/models are used estimating ecosystem service values. Ecosystem Services and Trade-offs models are cited several times as several services assessments were developed but more simple approaches are also used (e.g. giving a reference value or a score to a land use). With those approaches it is possible to calculate and map ecosystem services (see Makovnikova et al., 2019; Brady et al., 2015; Portifirio et al., 2010) but also to simulate different land uses, landscapes, agricultural practices, land covers in order to optimize/enhance one or several services (i.e. identify trade-offs) (see Rendon et al., 2020; McDounough et al., 2020; Steinhoff-Knopp and Burkhard, 2018; Inkoom et al., 2018; Kauffman et al., 2014).
Using those methods, it is also possible to quantify the effects of land use changes on ecosystem services. Seven papers worked on past and current data on land uses (extracted from databases) or to forecast the effects of future changes worked on scenarios. The differences in ecosystem services between 2 land use situations can then be calculated and mapped. The papers focused on the following ecosystem services and how they are modified with land use changes: primary production (Petrosillo et al., 2013), air purification (Wangai et al., 2019), water regulation (Wangai et al., 2019, Stammel et al., 2018, Sturck et al., 2015, Le Maitre et al., 2014) and purification (Stammel et al., 2018, Laurencova et al., 2015), carbon sequestration (Sturck et al., 2015, Laurencova et al., 2015) and habitat provision (Stammel et al., 2018, Cervelli et al., 2017). Assessment were made at different scales: local (e.g urban and peri-urban areas of a city), watershed or natural reserve area, country or even EU levels (Sturck et al., 2015). Such approaches may be used for land and landscape planning (see Vrebos et al., 2020, Knoke et at al., 2016, Speziale and Geneletti, 2014, Koschke et al., 2012).
Hasan et al. (2020) made a review on the effects of land use changes on the provision of ecosystem services. They demonstrated that most of the research reveals a negative impact of LUC on ecosystem services despite research gaps related to methods. Concerning soil properties and soil erosion, they declared that even if soil plays an important role in providing ecosystem services, research during the 1990s rarely studied the relationship between ecosystem services and soil properties. Among the available publications it seems that human dominated LUC increased soil degradation, soil erosion, nutrient loss, and organic matter content and at the same time increased leaching loss of nutrients. These changes, decreased agricultural productivity, water supply, freshwater ecosystem quality, and reservoir storage capacity.

The 22 articles address the following major issues:

(i) Methodological aspects:
- Methods developed for quantifying ecosystem service use remote-sensing data and/or geographical information system software,
- Data can either come from measurements or from models (e.g. use of RUSLE equation, of crop or hydrological models to estimate erosion, biomass production or water flows)
- When not modelled, data come from existing databases available at different scales (e.g. on land use, on yields, on carbon stocks, on erosion rates, on water flow…),
- Using scenarios (e.g. changes in land use, in agricultural practices, in land cover) several calculations and maps of ecosystems services are produced. Such simulation will help in optimizing a service or a bundle of services.

(ii) Investigated land uses:
- Main developments were made in agricultural land use but forests and natural land uses are also investigated, as well as cities / peri-urban areas,
- In agricultural situations, different systems (e.g. agroforestry, tillage/no tillage) and/or practices (e.g. cover crops, organic amendments) are compared and resulting ecosystem services as biomass/food production, carbon storage, erosion prevention, water purification… are assessed.

This may help in selecting best practices and/or for designing systems that optimize certain ecosystem services,

- In forest and natural areas, the assessment of ecosystem services can support the fact that any land use changes will impact the provision of services and/or that renaturation is needed to recover previous situation
- In cities and on peri-urban areas, the assessment of ecosystem services is generally used for land planning and identifying areas to be preserved (e.g. to regulate floods, store carbon, clean air).

(iii) Main services investigated are related to provision (biomass production) or regulation (e.g. carbon sequestration, regulation of water fluxes of quality) services. One paper was found dealing with cultural services.

- **Main actors publishing on the topic**

Mainly European research organisations can be observed (from Germany, Netherlands, Italy). China and Australia also published in this field of research.

<u>Knowledge domain: Awareness, training & education</u>

No articles were found. There is no existing knowledge regarding “Awareness, training & education” related to ecosystem services increase.

<u>Knowledge domain: Science based policy support</u>

Five articles were found on how the concept of ecosystem services may support several policies, such as land use/land management/spatial planning policies (Furst et al., 2017; Viglizzo et al., 2012; Eppink et al., 2012), agricultural policies (Horrocks et al., 2014) or biodiversity conservation policies (Zang and Ouyang, 2019). These are position papers pushing that concept as a way to support, objectivate and share decisions at different scales, from local to national situation.
Eppink et al (2012) stated that the concept of ecosystem services can be an instrument for designing better land management policies. Ecosystem services studies are inter- or transdisciplinary projects that combine scientific disciplines in their analysis of interacting ecological and socio-economic systems. In that sense collaborative research programmes improves the chances of successful and shared policies.
Concerning land management and land planning, Furts et al. (2017) describe how ecosystem services can contribute to characterize the interactions between humans and nature on different temporal and spatial scales while integrating cross-scale effects in trade-off analyses. They reveal the interdependencies between policy sectors, spatial and land-use planning and conclude that only a strategic and concise use of ecosystem services throughout all decision levels will help to create maximum benefits for harmonizing policy, planning and management instruments supported by intervention measures for the sake of sustainable development.
Viglizzo et al. (2012) note that the notion of environmental governance is spreading across the world and that policy makers, land-users, stakeholders and scientists should recognize that ecosystem services will probably be at the centre of future land-use policies, even if current methodological shortcomings for ecosystem service valuation and monitoring are not today enough developed nor stabilized (see also part on modelling). Despite still being uncertain, both economic and bio-physical values provide a rough metrics for ecosystem services that can be useful to compare with social and economic indicators and make decisions.

<u>Knowledge domain: Institution & governance</u>

No articles were found. There is no existing knowledge regarding “Institution & governance” related to ecosystem services increase.

Knowledge domain: Specific regions

6 articles were found, 2 dedicated to Mediterranean areas (Guerra et al., 2016 and Segre et al., 2019), one to mountains (Pérez-Suarez et al., 2018), 2 others to urban areas (Herrmann et al., 2017 in the USA and Canedoli et al., 2020 in Italy) and the last one to islands (Zhang and Xiao, 2020).

For Mediterranean areas, Guerra et al. (2016) studied the effects of European Union policies on the deliverance of one ecosystem service (SEP: soil erosion prevention) in Portugal on sylvo-pastoral systems. They developed a framework linking policies with ecosystem services provisions, used time series analyses of several indicators as land cover or grazing intensity and modelled erosion according to USLE equation. Each land cover was associated with its changes and capacity to prevent erosion. They demonstrated that as a consequence of headage payments for cattle, the agricultural policies had a significant effect in the density and renewal of the tree cover, resulting in drastic effects for the provision of the SEP service. These effects are more significant after 1986 with the implementation of several Common Agricultural Policy instruments focused on increasing the modernization and productivity capacity of farm systems. They emphasized the need for spatially informed agricultural policies adapted to the social-ecological context of each region. Their framework based on spatially explicit ecosystem regulating service indicators shown to be sensitive to changes in policy and can be used for strategic assessments, both in long-term monitoring schemes or ex-ante evaluations. Segre et al. (2019) compared in a multi-taxa and landscape approach the cost-effectiveness of uncultivated field margins and semi-natural patches in Mediterranean areas. They found that field-margins increased biodiversity compared to cultivated land and that the biodiversity was near that recorded in semi-natural patches. Of course, biodiversity benefits of field-margins varied across seasons and taxa but an increased potential biological pest-control was observed. However, field-margins were associated with revenue loss in most crop types, leading to lower cost-effectiveness compared to creating large semi-natural patches but in a few crops types the reverse effect was observed. Such results indicate that there is no one-size-fits-all agri-environmental policy. Measures need to be locally tailored (e.g. crop-specific) to maximize ecological and economic benefits at large spatial scales, while considering that in many cases setting aside contiguous areas for conservation is more cost-effective than field-scale wildlife-friendly practices.

In Mexico, studying the effects of extensive grazing on ecosystem services provided by soil, such as carbon and organic matter accumulation, carbon storage, and water infiltration, Pérez-Suarez et al. (2018) found that compared with controlled non-grazed areas the ecosystem services measured were modified and little reduced. Nevertheless, they concluded that extensive livestock ranching and resource conservation are not necessarily mutually exclusive. Herrmann et al. (2017) suited how urban soils may be the basis of many ecosystem services in cities by examining formerly residential vacant lot soils in 4 cities in the USA. By sampling and analysing deep soil cores from vacant lots they measured three ecosystem services: hydraulic conductivity for stormwater retention, topsoil depth and soil nitrogen (N) level for support for plant growth, and soil carbon (C) content for C storage. They conclude that vacant lot soils in cities are extensive natural infrastructures that can provide many benefits to neighbourhood, cities and at global scale by supporting multiple ecosystem services. Canedoli et al. (2020) studying urban parks in Milan evidenced high soil organic stocks comparable to those found in forest or pastures in the same region.

In China, Zhang and Xiao (2020) studied the spatial distribution and interactions of ecosystem services (cultural, provisioning and regulating) in East China's Zhoushan Archipelago and how this information may influence the island's sustainable development policy. The results show that the archipelago's total ecosystem services hold great potential but that there are significant trade-offs and synergy relations, which vary on different islands in the archipelago. They identified and located areas where the provisioning services show a negative correlation between cultural services and regulating services, indicating strong trade-offs between them and areas where synergies between cultural and regulating services might become priorities for future policies. The island planning policy proposed in this paper, based on the ecosystem services theory and sensitive to intra-archipelagic differences, contributes to efforts at island sustainable development by seeking to resolve tensions between economic development and environmental protection.

Knowledge domain: Specific sectors & practices

Two articles present how agroforestry can increase the ecosystem services of agricultural sector and developed quantification approaches. Tsonkova et al. (2014) developed an easy to use method, accessible to stakeholders, to facilitate comparison of ES provision with respect to different land use practices. This tool assesses five regulating services, i.e., carbon sequestration, soil fertility, erosion control, water regulation, and water

quality; and one supporting service, i.e., habitat provision. Such approach was used to compare different scenarios for conventional agriculture (CA) and alley cropping systems (ACS) with various tree proportions in Germany. The results, confirmed by related literature, suggest improvement in the ES provision of habitat, erosion control, soil fertility, water quality, and carbon sequestration by ACS as compared to CA.
Concerning carbon sequestration, Crous-Duran et al. (2018) developed an indicator based on the "carbon balance" resulting from the difference between the greenhouse gasses emitted (considered as negative values) and carbon sequestered (positive values) estimated in Mg CO2eq per Mg of food produced on one hectare of land for one year. Such indicator quantifies the global warming potential associated with sustainable intensification by integrating a process-based model with life cycle analysis and is able to estimate above- and below-ground biomass and soil carbon content. This methodology was tested in Portugal for wheat production under crop monoculture and agroforestry systems. They showed that agroforestry is a suitable practice for sustainable intensification compared to a crop monoculture as it just slightly decreased wheat yields whilst providing a positive carbon balance.

8. Societal challenge: improve disaster control

Knowledge domain: entire societal challenge

- **Interest in the topic**

2,527 scientific journal articles were identified related to disaster control improvement. The 2,527 articles were published between 1940 and 2020. There has been a significant increase in general attention in this area since 2008 (Figure 59). About half of the existing articles on the topic (1,143/2,527, 45%) were published in the last five years between 2016 and 2020. The number of articles being published reaches 313 in 2020.

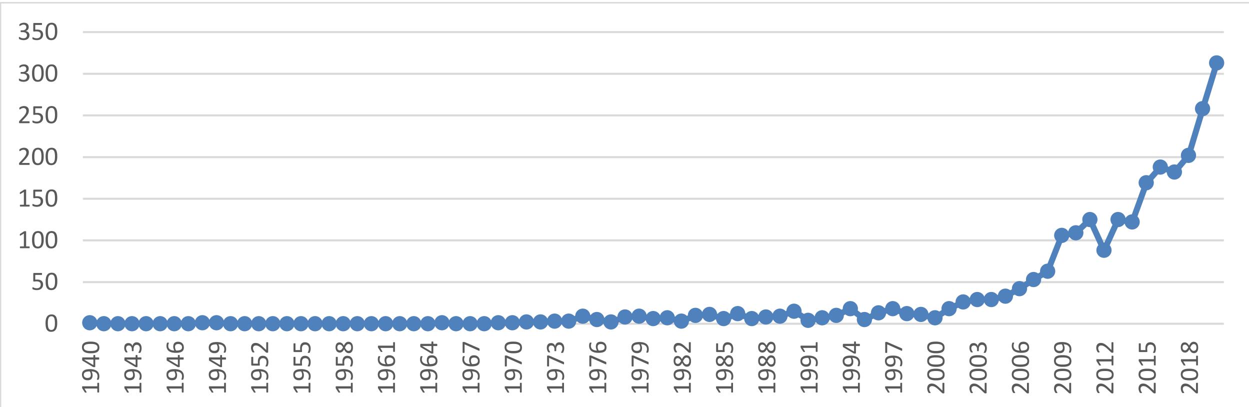


Figure 59: Chronologic number of articles since 1940 published on "improve disaster control"

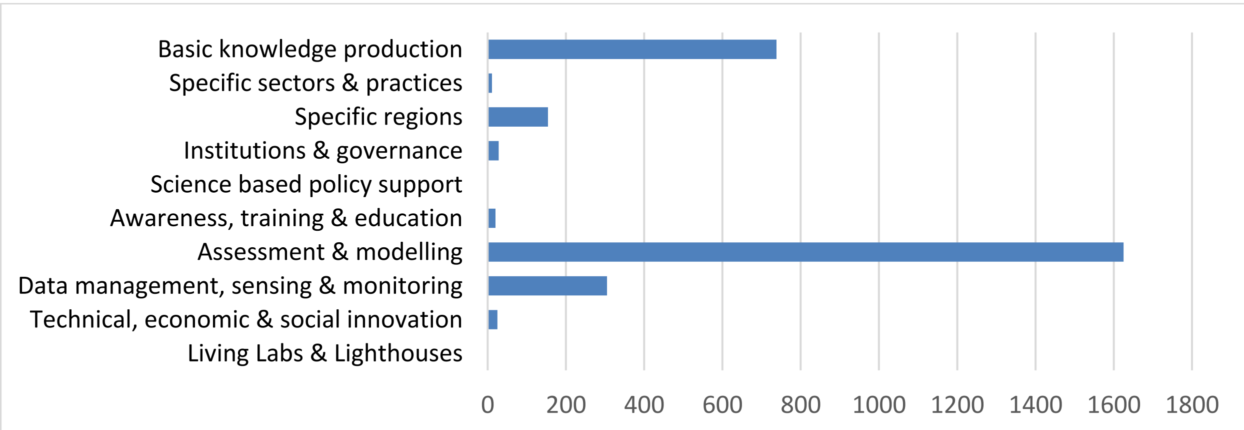


Figure 60: Number of articles per SMS knowledge domain

A deeper analysis was done to get an overview of the different knowledge domains which were addressed in the 2,527 articles (Figure 60). More than half of all articles (1,625/2,527, 64%) have a focus on the knowledge domain “assessment & modelling”. The other knowledge domain which is substantially addressed is “specific regions” with 12% of all articles. 738 articles are on basic knowledge production, not related to a particular knowledge domain.

- **Existing research & knowledge**

The full corpus was analysed textually using CorTexT to review the themes addressed in the 2,527 academic articles. Overall, the main terms found in the articles are “land use”, “flood risk”, “flood control”, “soil moisture”, “water resource”, “risk management”. The map of the articles’ textual content is presented in Figure 61. The main terms used in the 2,527 articles are distributed in five clusters 1: “risk management”, 2: “water resources management”, 3: “soil water”, 4: “flood frequency”, 5: “land management”. The clusters have very few interconnectivities and do not overlap.

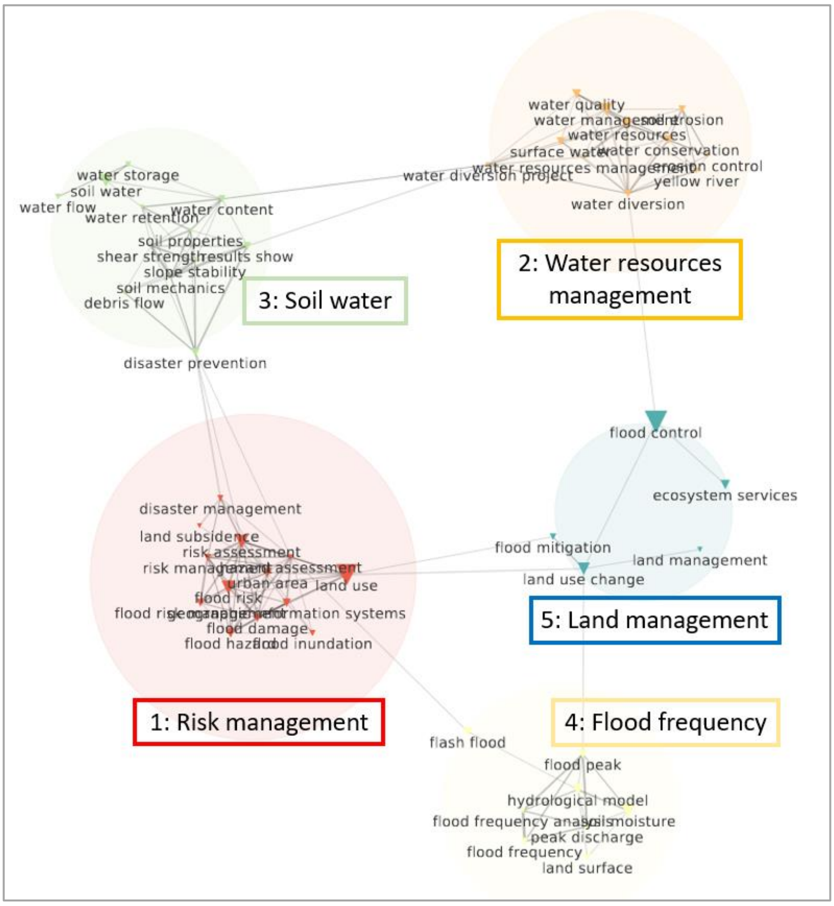


Figure 61: Overall cluster map of the main terms used in the full corpus (2,527 articles)

Within the topic area ‘improve disaster control’, all four considered topics, floods, droughts, wildfires, and mass movements, were discussed in articles. From 1940 till 2020, the main focus area was flood control, drought monitoring and landslide management. In the last two decades, wildfire has also come into consideration due to more frequent and more extensive wildfires globally. With time, more adequate and proper disaster control methodologies have been developed. Previously, it was all about land management, while nowadays, more computer-based methods are developed to forecast and map disaster areas. In the last few decades, it is reported that the destruction done by floods has increased. The spatio-temporal variability of large floods in Europe from 1985-2009 has been described, and the main reasons behind the increasing flood risk in Europe have been discussed. Many adaptation strategies have been suggested by taking private damage reduction measures and proper land use planning. The efficiency of these measures was proved in Germany during the floods in 2002. It has also been suggested to use green infrastructure planning and ecosystem service management for flood control. Since proper drainage systems are required for flood control, optimal ecological management practices have been proposed to reduce the requirement of large capacity drainage channels. Good agricultural practices which increase soil water retention capacity have been recommended. A new strategy has been developed for flood forecasting, while a map template has been developed to improve flood risk maps and increase awareness. Moreover, China's structural and non-structural measures for flood control have been discussed to control flash floods and urban flooding. It has been reported that soil-bioengineering is an effective way to stabilize landslide hazard sites. Through spatial analysis of soil geomechanical properties, it is possible to detect landslide-prone areas. A model based on soil thickness maps has been proposed to improve shallow landslide modelling. An article has identified the drought limit of the ten most important tree species in Germany. It has been found that dominant trees are better in adaptation, thus it has been encouraged to remove suppressed trees and promote dominant trees under drought conditions to stabilize forests. For wildfire protection, a model named WHAMED has been presented to find out the prioritized lands for mechanical thinning. By integrating woody vegetation, crops, and livestock, it has been suggested that agroforestry systems would be useful to manage the wildfires in European Mediterranean countries.

- **Main actors publishing on the topic**

Almost one third of all articles (668/2,527, 26%) were carried out in China (Figure 62). A substantial proportion of the articles were also conducted in the United States (546/2,527, 22%). In Europe, the United Kingdom followed by Germany and Italy are the countries who published the most articles (respectively 8%, 5% and 4%). Eight European institutions were involved in the production of at least 20 distinct articles each on the topic (Figure 63). The main institutions involved in Europe are Technische Universität Wien (Austria), University of Oxford (United Kingdom) and Vrije Universiteit Amsterdam (Netherlands), with respectively 24, 23 and 23 articles.

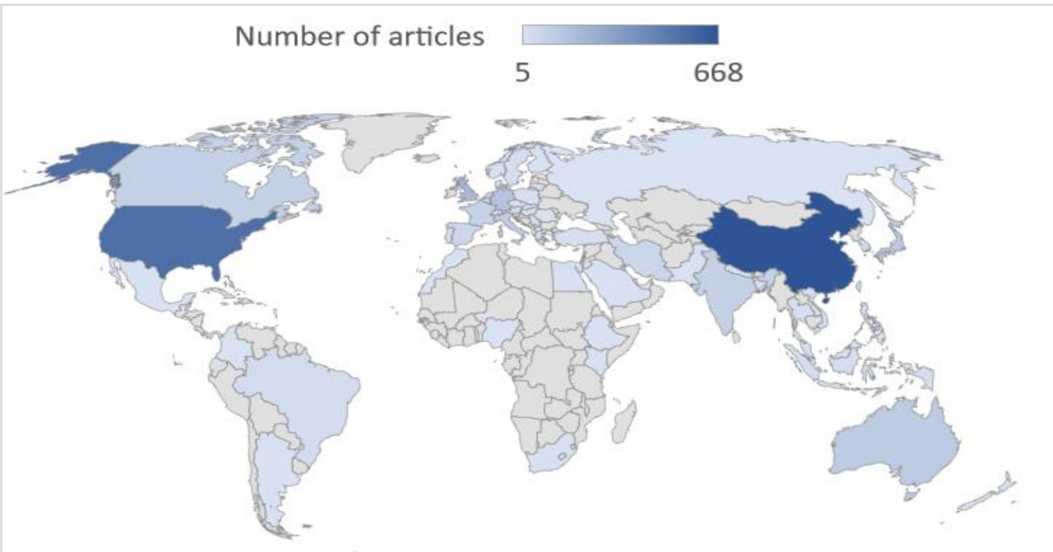


Figure 62: Map representation of the countries where at least 5 articles were published

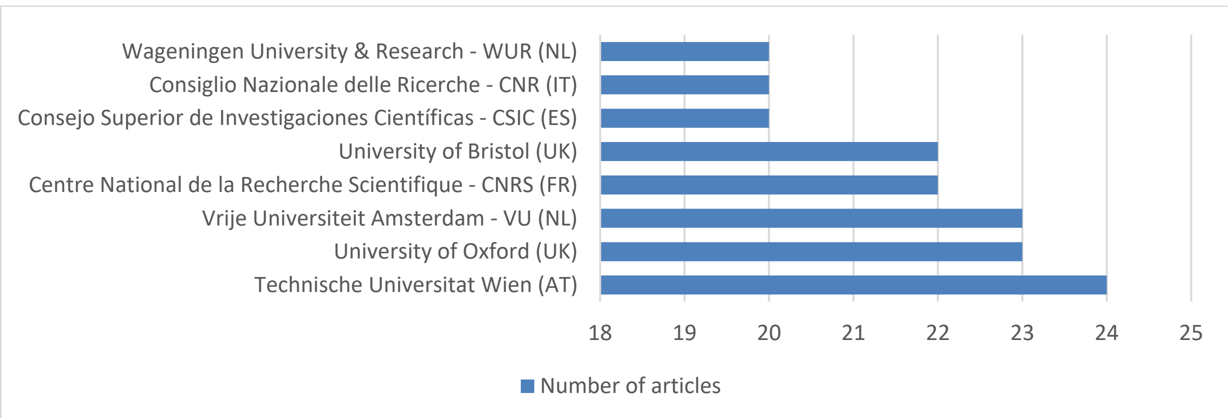


Figure 63: Main institutions in Europe who published more than 20 articles on the topic

There are 7 communities of authors (represented by clusters) with 5 clusters having very strong interconnectivities with one and another (Figure 64). These 5 clusters overlap. The authors from the 5 clusters are mainly from China and tend to publish in big communities of authors. The interactions with the two other communities of authors from Europe and the United States are scarce. Wang Y. (Sichuan Agricultural University, China) and Wang J. (Zhengzhou University, China) are the main authors in number of publications (respectively 33 and 28 publication). There are about 40 authors with more than 10 publications.

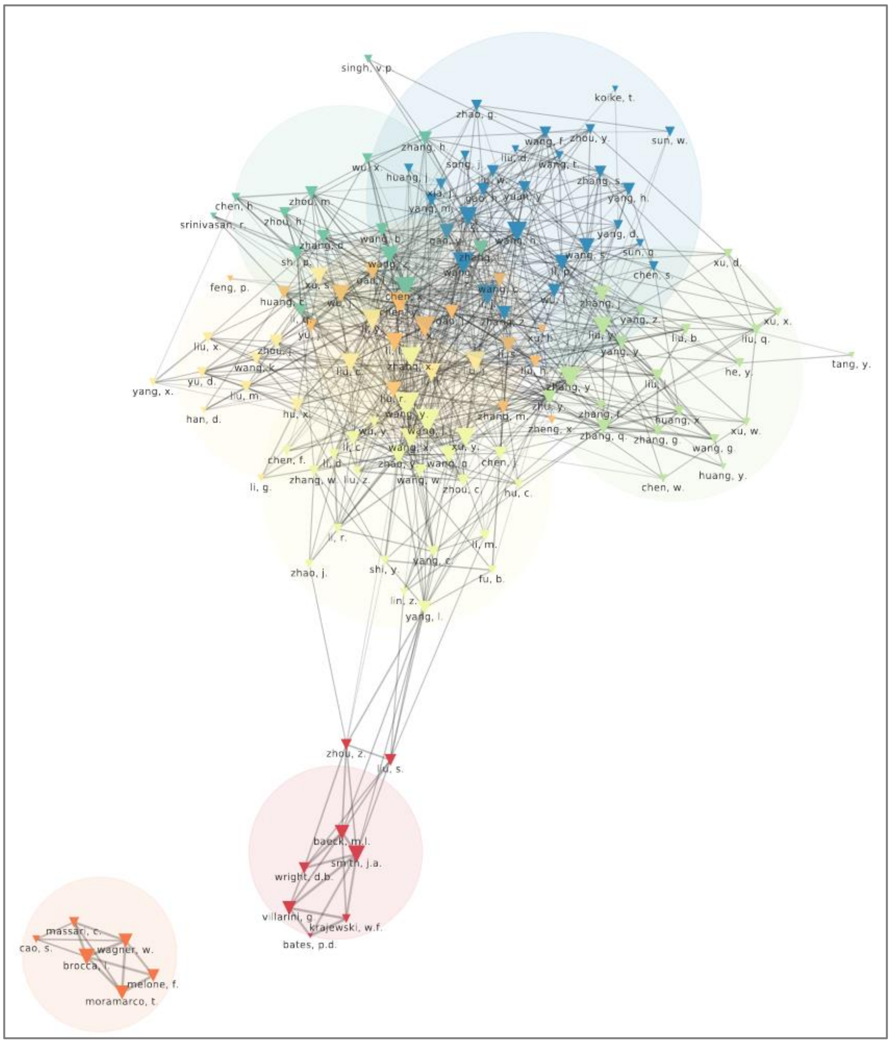


Figure 64: Map representing the interconnectivities between the main authors

<u>Knowledge domain: Living Labs & Lighthouses</u>

Within the topic area 'Improve disaster control', only one review article from 2020 was found related to "Living Labs & Lighthouses", which addresses forestry issues related to changing climate (i.e. droughts and wildfires). The article proposes that forest projects can serve as 'Living Labs' to adapt forests to droughts and future changes. The one review article was written by a single author, Tamir Klein, from the Weizmann Institute of Science, Israel.

<u>Knowledge domain: Technical, social & economic innovation</u>

- **Interest in the topic**

25 articles relating to disaster control with a focus on "technical, social & economical innovation" exist on Scopus. They were published between 1976 and 2020. 28 % of the existing articles on the topic (7/25) were published in the last five years (2016 to 2020).

- **Existing research & knowledge**

Among the 25 published articles, only three topics: floods, wildfires, and mass movements (landslides, debris flows, etc.) were discussed, but there were no articles on droughts. Most of the research focused on flood

control (22 articles), only two articles focused on mass movements and one article on wildfires. Mostly, innovations and technological advancements on flood control and disaster mitigation have been discussed, such as constructing modern flood walls and embankment dams, modern drainage systems, storm-water infiltration basin etc., to prevent damage from frequent floods. To get a more accurate floodplain model and to forecast floods earlier, it has been suggested to use satellite images, hydrological models, and GIS techniques. In 2008, an improved catchment modelling integrated with AI (artificial intelligence) to flood forecasting had already been demonstrated in Ore-mountains in Germany. A cooperative game theory has also been proposed to improve the water retention capacity of lands for flood protection. Moreover, a new approach has been discussed that focuses on sustainable land use as a strategy for mitigation of flood impacts. It has also been concluded that modern urban designs are not very effective regarding flood risks mitigation. A real-time dynamic warning technology was developed to warn against floods in mountain areas. As erosion in the catchment area is considered a major ecological problem, a method to record, analyse and predict the causes of erosion in a catchment area was suggested. Many innovations have been developed for erosion control, however, many with mediocre functionality (esp. in mountain areas). Thus, there is room for improvement. The technical and social problems of landslide disaster prevention and mitigation are also ongoing research hotspots. Currently, prevention measures are difficult and expensive. Recent advances that address the issue with more ecological focus on a landscape scale promise improved prevention measures. A survey on wildfires showed that open forests with low ground cover are better than dense forests or widely cleared areas. Local residents widely accepted controlled or prescribed fire as disaster control measures.
Throughout time, from 1976 till 2020, the focus has been both on flood control and mitigation through land management. During the last decade, wildfire management is getting more attention. At present, wildfires during summer times increase globally, causing loss of properties and endangering local ecology. Further, recently more emphasis has been given to urban planning and land management to prevent further flooding and wildfires.

- **Main actors publishing on the topic**

Worldwide, the United States, China, and Australia are the countries that published the most on this topic (in descending order). In the European Union, it is Germany, and Netherlands. The only article on forest fires is written by Ryan, R.L. (University of Massachusetts, United States) and the articles on mass movements are written by Cuff, J.R.I (South Canterbury Catchment Board, New Zealand) and Yue, Z.Q. (University of Hong Kong, Hong Kong).

<u>Knowledge domain: Data management, sensing & monitoring</u>

- **Interest in the topic**

305 articles relating to disaster control improvement with a focus on “data management, sensing & monitoring” exist on Scopus. They were published between 1984 and 2020. More than half of the existing articles on the topic (172/305, 56 %) were published in the last five years (2016-2020).

- **Existing research & knowledge**

The main terms used in the 305 articles are distributed in four clusters, 1: “risk management”, 2: “water management”, 3: “soil moisture”, 4: “remote sensing”. The clusters interconnect all with each other.
Among the articles, most of the research has been done on flood control, drought assessment, mass movements (landslides, debris flows, etc.) and little on wildfires. The establishment of embankment and flood reservoirs using GIS system was a main topic related to flood control. Further tools and methods include e.g. soil moisture dynamics, hydrological models with high-resolution remote sensing system, HEC-HMS (Hydrologic Modelling System from Hydrologic Engineering Centre), lysimetric data and GPS signal to get accurate information for earlier flood forecasting. The European Flood Awareness System (EFAS) has observed remotely sensed soil moisture and cut false flood alerts, and improved near-real time flood forecasting in large catchments. It was proposed to use a higher number of data points for interpolation to increase spatial resolution in soil moisture measurement and flood forecasting accuracy. Further, remote sensing and hydrological modelling were integrated to predict flash floods in arid regions with scarce data availability. Most data management and monitoring aimed at classifying drought severity, determine characteristics, improve monitoring systems, and to assess mitigation measures. Moreover, emphasis has been given to irrigation water

management using a genetic algorithm (GA)-based model. Furthermore, remote sensing data, eco-hydrological land data and GIS analysis have been proposed to monitor drought properly that might help take adequate measures. GIS and remote sensing techniques have been developed to map the landslide susceptibility, and with time new techniques and new idea has been approached, e.g. soil moisture condition measurement with GIS or with Advanced SCATterometer (ASCAT) system to forecast landslides, or changes in vegetation cover to improve landslide control. Also, an early landslide detection method based on the D-InSAR technique has been proposed. Classic in-field data collection for safety control of slopes remains labour intensive and is thus restricted to small areas. For wildfire risk mitigation, data were processed using high-resolution remote sensing, GIS, and PESERA model, including land use planning and land degradation control due to wildfire.
From 1984 till 2020, the main focus area was flood control, drought monitoring and landslide management. In the last decade, wildfire has also come into consideration due to more frequent and larger wildfires globally. GIS-based techniques were dominantly used in all sector.

- **Main actors publishing on the topic**

Worldwide, China, France, Germany, Greece are the countries that published most on this topic.

Knowledge domain: Assessment & modelling

- **Interest in the topic**

1,625 articles relating to disaster control improvement with a focus on "assessment & modelling" exist on Scopus. They were published between 1970 and 2020. More than half of the existing articles on the topic (837/1,625, 52 %) were published in the last five years (2016-2020).

- **Existing research & knowledge**

Among the articles found, all the four topics: 'floods, wildfires, mass movements (landslides, debris flows, etc.) and drought' have been discussed. Modelling flood plains, assessment of flood mitigation and risk analysis have been major research areas. One article has assessed the seasonal flood risk. It has been suggested to use earth observation technologies and geographical information systems in flood mapping. A method named 'Inondabilite' has been proposed to produce easy-to-understand maps to prevent flood risks. An assessment in a catchment in Germany has been done to show how changes in land use can influence flood runoff. A flood risk assessment in the river 'Elbe' was done to show the expected annual damage. A stormwater pollutant model has been developed to calculate the pollutant loadings during floods. For landslide hazard and risk assessment, a Europe-wide landslide susceptibility map has been modelled. It has been discussed that sites which are susceptible to landslides caused by soil erosion can be localized by using the Revised Universal Soil Loss Equation (RUSLE) model. It is also reported that vegetation is an effective way to prevent landslides. Modelling soil moisture fluxes and slope stability are standard methods for slope stability assessment. By analysing the soil-moisture index, a model has been developed for early drought warning. It has been suggested to use water-efficient technology in agriculture to increase resilience to droughts. Summer dormant plants are better at controlling the soil profile's water content in drought-prone areas. A recent article has discussed the early warnings of flash drought development. A model has been proposed for forest fire prevention, production risk scenarios, and evaluation of environmental impacts. Another dynamic model has been demonstrated to forecast the prioritized locations for future mechanical thinning as a method of wildfire mitigation. It has been discussed to increase private wildfire mitigation measures. Moreover, a modification of the Pan-European Soil Erosion Risk Assessment (PESERA) has been proposed to control wildfire. In a recent article, the characteristics of the fires in the USA, Brazil, and Australia have been analysed.
From 1970 till 2020, the focus has been both on flood control and land management. Drought management and wildfire control are more of a recent topic. The interest has been changing depending on the present situation.

- **Main actors publishing on the topic**

Worldwide, Australia, Belgium, Canada, China, France are the countries that published the most on this topic. Worldwide, authors publish in large communities from different institutes with many co-authors.

Knowledge domain: Awareness, training & education

20 articles relating to disaster control improvement with a focus on "awareness, training & education" exist on Scopus. They were published between 1988 and 2020. More than half of the existing articles on the topic (11/20, 55 %) were published in the last five years (2016-2020).

Most of the articles covered the topic 'floods' and 'mass movements' (landslides, debris flows, etc.), while one article addressed both topics combined. Two articles addressed wildfires. No article focused on 'droughts', but they were discussed in an article on land management. Emphasis has been given to flood control and educating the people to take proper measures when floods occur. Strategies have been developed on international levels, such as the 'EU sustainable development of floodplains (SDF)' to better protect catchment areas of rivers that cross-national borders (e.g. the river Rhine). Knowledge on the construction of embankment dams, flood protection walls, modern drainage systems, etc., is discussed to prevent damage from frequent floods. It has been noted that the public has a weaker perception of the connection between land management and soil erosion. As economic losses through soil erosion, (e.g. reduced soil quality or fertility) are felt gradually over a long time, they are usually not considered. The articles on wildfires suggested creating more public awareness and educating people on setting-controlled fires to prevent uncontrolled fires. It has been discussed that through proper education on land management and forest fires, land managers will be aware of the adverse effects of unsustainable land uses and be able to take proper measures when needed. Moreover, it is also reported that proper education and training in sustainable land management can contribute to drought mitigation.

While from 1988 till 2010, the main focus was on flood management, from 2012 wildfires and land management started to gain attention. Although protection against floods has been the main focus in the last three decades (1988-2020), other natural disasters are also getting attention since the last decade. Despite beginning awareness and educational research from 1988, an article from 2016 has shown that people are still largely unaware of measures for disasters control and prevent.

Worldwide, United States, Netherlands, Bangladesh, China, and Germany are the countries who published the most on this topic (in descending order). In the European Union, aside from the Netherlands and Germany, it is Austria, Romania, and Spain. Worldwide, the following institutions are the prominent publishers on this topic: United States Department of Agriculture – USDA (United States), Agricultural Research Service – ARS (United States) and Bangladesh University of Engineering and Technology (Bangladesh).

Knowledge domain: Science based policy support

Only one article from 2013 on "science-based policy support" was found within the topic area that addresses flood control through wetland preservation in the United Kingdom (UK). It discusses different science-based policies in the UK, as linked to flood control through wetland management. The article provides an assessment of wetland protection for improving related ecosystems and their services, including flood control. The article was published by E. Maltby (first author) from the University of Liverpool and representatives of four other UK research institutions. Considering the small number of identified articles on the topic, there is no emerging main R&I actors.

Knowledge domain: Institutions & governance

- **Interest in the topic**

28 articles (from 2001-2020) relating to disaster control with a focus on "institutions & governance" exist on Scopus. More than half of the existing articles on the topic (18/28, 64 %) were published in the last five years, between 2016 and 2020.

- **Existing research & knowledge**

Among the 28 articles found, 19 articles discussed the topic area 'floods', 4 articles were on 'wildfires', 3 articles on mass movements (landslides, debris flows, etc.) and 1 article on 'drought'. The main focus was on flood control, with some overlap with land management. Many cultural problems (e.g., the culture of institutional fragmentation, culture of conflict, and land development) have been identified contributing to increased flood damage. It has been pointed out that the Tokyo governing authority's active restoration and development projects in 1950 have improved flood control of previously flood prone areas. It has also been noted that the laws should focus both on water scarcity and flood control at the same time. The interaction

between humans, ecosystem, and water systems in the floodplain and urban areas also influences the frequency and severity of floods. It has been discussed that interaction between government agencies and citizens can build trust among stakeholders while planning flood control policies. Moreover, simples and low-cost technologies have been recommended in flood analyses for the governments in developing countries.
From 2001 till 2020, the focus has been mainly on flood control and mitigating environmental and social damage. During the last two decades, wildfire management is also getting attention because of climate change. But, with climate change, different parts of the earth are observing different weather patterns. Although frequent drought brings wildfires, only one article from 2014 has focused on drought disaster mitigation. Nowadays, more emphasis has been given to urban planning and land management to prevent further flooding and to control wildfires.

- **Main actors publishing on the topic**

Worldwide, the Netherlands, China and the United States are the countries that published the most on this topic (in descending order). In the Europe, aside from the Netherlands, it is Germany, Czech Republic, and Switzerland. The institutions in Europe which published the most on this topic are Wageningen University & Research - WUR (Netherlands) and Utrecht University (Netherlands). Considering the small number of identified articles on the topic, there is no emerging authors. All four articles on wildfire have been written by different authors from different institutes in the United States.

<u>Knowledge domain: specific regions</u>

154 articles relating to disaster control improvement with a focus on “specific regions” exist on Scopus. They were published between 1979 and 2020. About half of the existing articles on the topic (72/154, 48 %) were published in the last five years (2016-2020).
Among the articles found, all four topics: ‘floods, wildfires, and mass movements (landslides, debris flows, etc.), and drought’ are discussed. Flood management and landslide control have been the main focus, while drought management is getting more focus recently. From 1979 till 2020, the focus has been both on flood control and land management. During the last decade, wildfire management is also getting attention because of climate change. Research has been conducted primarily on Mediterranean regions, but articles on mountainous and coastal regions are also available.
Worldwide, Canada, China, France, Germany, Greece, Spain, and United States are the countries that published the most on this topic.

<u>Knowledge domain: Specific sectors and practices</u>

11 articles relating to disaster control improvement with a focus on “specific sectors & practices” exist on Scopus. They were published between 1993 and 2020. More than half of the existing articles on the topic (6/11, 54 %) were published in the last five years (2016-2020).
Among the articles found, all four topics: ‘floods, wildfires, and mass movements (landslides, debris flows, etc.), and drought’ are discussed. Some articles have overlapping topic areas. Eco-engineering approaches (e.g. planting trees) are proposed for erosion control and improved water supply during droughts. It has been discussed that deep-rooted intercropping plants and shallow-rooted crops can be a helpful drought management strategy in dry areas due to a hydraulic lift in soil. It has also been found that droughts can be mitigated through crop diversification. Other suggested drought mitigation measures such as harvesting rainwater and agroforestry systems. Agroforestry systems can increase heterogeneity in soil microbial biomass, which eventually escalates microbial resilience against drought stress. It is also reported that wildfires are observed less in agroforestry areas, which mix livestock and trees, as it removes part of the dry ground-level vegetation through livestock grazing. Initially (1993), the main focus area was on flood control, which changed by 2004 towards drought mitigation. Wildfire management is a more recent topic. The reason behind this is the increasing global temperature resulting in severe droughts in many areas, eventually causing massive wildfires.
Worldwide, the United States and the United Kingdom are the countries that published the most on this topic (in descending order). In the European Union, it is Italy, Greece, Spain, Finland. The United States have published articles on flood and drought management, while the United Kingdom has published articles on wildfires and land management. All the articles were published by different authors from different institutes.

Knowledge domain: Basic knowledge production

There is a total of 738 articles on basis knowledge production, not related to any knowledge domain and in relation to disaster control improvement. These are articles were published between 1940 and 2020. There was a significant increase in general attention in this area within the last years. 32 % of the existing articles (238/738) on the topic were published between 2016 and 2020.

The main terms found in the articles are “land use”, “river basin”, “water resources”, “soil water”, “water diversion”, “soil erosion” and “soil moisture”. The map of the articles’ textual content is presented in Figure 65. The main terms used in the 738 articles are distributed in five clusters, 1: “Water resources”, 2: “Water quality”, 3: “Drought”, 4: “Water diversion”, 5: “Soil erosion”. The clusters have few interconnectivities and no overlaps between them.

Almost one quarter of all articles (168/738, 23 %) were carried out in China. A substantial proportion of the articles were also conducted in the United States (159 articles). In Europe, the United Kingdom followed by Germany are the countries who published the most articles (respectively 8 % and 6 %). The main institutions involved in Europe is the University of Oxford (United Kingdom) with 6 articles.

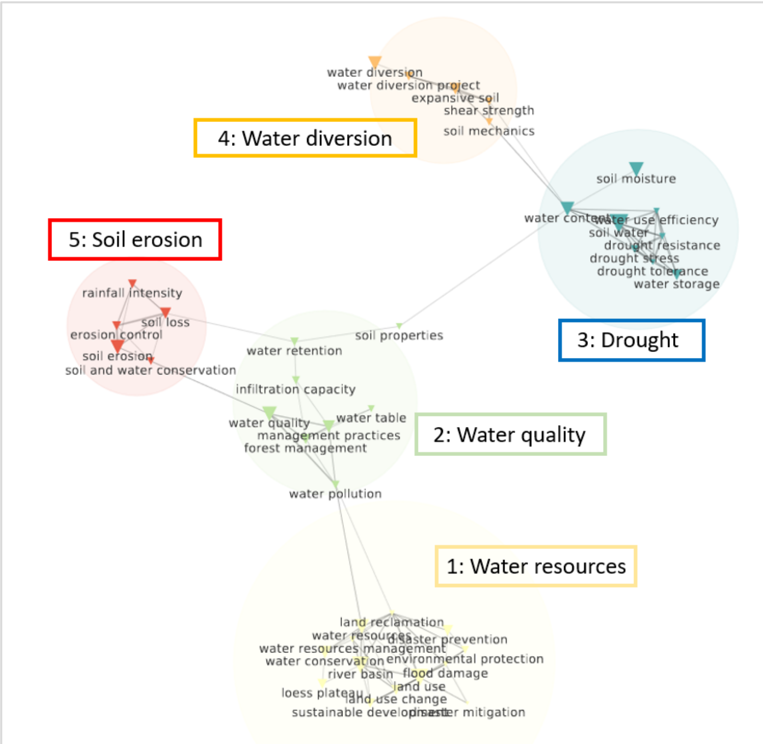


Figure 65: Cluster map of the main terms used in the full corpus (738 articles)