European Commission

FORESIGHT

Mission Area: Soil Health and Food

Foresight on Demand
Brief in Support of the
Horizon Europe Mission Board

Research and Innovation

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Mission Area: Soil Health and Food

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Foreword

In 1969, the first human set foot on the moon. "A small step for a man. A giant leap for mankind" was what audiences across the world heard. The Apollo mission showed the world what directed science, research and innovation could make possible. It proved what humankind can achieve in not even a decade, by setting a clear goal, which manages to capture public imagination, and by investing the necessary resources into it.

The mission approach, directing and combining different resources and actors towards a common goal, is becoming a key element of transformative R&I policies in a world of increasing global challenges. The Commission introduced missions as a new instrument in Horizon Europe and appointed Mission Boards to elaborate visions for the future in five Mission Areas: Adaptation to Climate Change, Including Societal Transformation; Cancer; Healthy Oceans, Seas, and Coastal and Inland Waters; Climate-Neutral and Smart Cities; Soil Health and Food.

EU R&I policy missions are ambitious, yet realistic and most of all desperately needed in light of today's challenges. They endeavour to bring together policies and instruments in a coherent, joined-up approach, and tackle societal challenges by setting and achieving time-bound, measurable goals.

In September 2020, the Mission Boards handed over their reports to the Commission. Five foresight projects carried out in close interaction with the Boards supported their work. These projects provided advice on trends in the respective areas, elaborated scenarios on alternative futures, scanned horizons, and made aware of weak signals, and emerging new knowledge and technology, helping the Boards imagine how the future may evolve and how to shape it.

With the launch of the five Missions in Horizon Europe, we are making this valuable work available for the broader public. I am confident that the comprehensive material, creative ideas and exciting examples in the Mission Foresight Reports will prove useful to all those engaged in the Horizon Europe Missions.

Jean-Eric Paquet
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Table of Contents

List of Tables

List of Figures

BACKGROUND AND ACKNOWLEDGEMENTS

Missions and Horizon Europe

The notion of "missions" as one of the novel cornerstones of Horizon Europe, the European Framework Programme for Research and Innovation 2021-2027, was introduced in the course of the programmatic debates about the orientation of the EU's future R&I policy, in particular through the Lamy Report. This report, which was presented in July 2017, recommended adopting "a mission-oriented, impact focused approach to address global challenges". Missions would serve as targeted and longer-term ambitions around which to build a portfolio of Horizon Europe research and innovation projects.

The idea of mission-oriented research and innovation was subsequently further specified through various studies and reports, in particular also by two reports by Mariana Mazzucato, which inspired policy debates at European as well as national level. In line with this preparatory work, missions shall have a clear R&I content EU added value and contribute to reaching Union priorities and Horizon Europe programme objectives. They shall be bold and inspirational, and have scientific, technological, societal and/or economic and/or policy relevance and impact. They shall indicate a clear direction and be targeted, measurable, time bound and have a clear budget frame.

As a result of debates at European level, the European Commission (EC) proposed five initial broad Mission Areas in autumn 2018. This initial list was subsequently adjusted in interaction between the EC and Member States, leading to five Mission Areas:

i) Adaptation to climate change including societal transformation,
ii) Cancer,
iii) Healthy oceans, seas, and coastal and inland waters,
iv) Climate-neutral and smart cities, and
v) Soil health and food.

As spelt out in the specific request, these missions will be anchored in the pillar "Global Challenges and Industrial Competitiveness", but may well reach out to the other pillars of Horizon Europe.

Within each of these Mission Areas, a limited number of specific missions shall be defined in the context of the next framework programme, with a first set of missions to be launched in 2021. To this end, the EC has established Mission Boards of about 15 outstanding members for each of the five Mission Areas. Mission Board members were appointed in August 2019 and they started their work in September/October 2019. They presented their recommendations to the EC at the EU R&I days in September 2020. The titles and descriptions of the actual EU Missions launched by the European Commission are found here: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/missions-horizon-europe_en

Foresight on Demand

Against this background, a request for services with five lots was put out under the Foresight on Demand Contract (FOD) of DG R&I to support the five Mission Boards. The five projects started in autumn 2019. For around a year they worked for and with the Mission boards, providing foresight expertise and methodology. They were aimed to feed the reflections of the Mission Boards with future-oriented inputs on challenges and options in the respective areas.

With the launch of the missions in Horizon Europe, this valuable work is now public as a part of the Foresight Papers Series. The five mission foresight reports give a detailed overview of the alternative futures, and the future perspectives in science and technology in the five mission areas build part of the basis for the considerations of the Mission Boards.

They may serve as background material and a source for examples and ideas for coming mission activities.

Mission foresight project "Soil Health and Food"

The foresight project "Support to the Mission Board Soil Health and Food" (Framework Contract 2018/RTD/A2/OP/PP-07001-2018-LOT1) aimed to provide forward-looking evidence to support the Mission Board in the drawing of a shared vision, making the most of the geographical and disciplinary diversity of its members. Adopting a long-term perspective, the project first offered insights to better understand the drivers, trends and weak signals with the most significant potential to influence the future of soils health and food. This analysis served as background for the organisation of a Scenario workshop with the Mission Board in which three different and plausible scenarios at 2040 were sketched. In the final step, the FOD team built on existing system-thinking knowledge to identify concepts, solutions, and practices able to promote systematic change in the soil health and food sector.

The overarching research goal is to achieve 'healthy soils' across ecosystems for food, nature and climate. The concept of ecosystem services provided the opportunity of conceptually linking complex processes in soils to economic and policy thinking. In line with the Mission Board's works/objectives, the project took a holistic and systemic view of soil health and food, one that goes beyond the assessment of the main effects of individual actions by focusing on their interactions, feed-back and feed-forward loops.

The report provides an overview of systems thinking, across scales; current synthesis of the linkages between management practices with soil indicators, and definitions and an outline of criteria for Living Laboratories. As such, it provides information that can help to enhance the vision for the soil health and food Mission, outlined by the Mission Board in "Caring for Soil is Caring for Life" (2020).

Mission Area: Soil Health and Food.
Foresight on Demand Brief
in support of the Horizon Europe Mission Board

Executive Summary And Introduction

This report aims at supporting the Mission Board on Soil Health and Food in populating the building blocks of the mission area and in the identification of priorities.

The starting point is the ***Mission Board report 'Caring for soil is caring for life'***, which sets the overarching goal of achieving 75% of all soils healthy by 2030, as indicated by improvement in the 6 soil health indicators, according to benchmarks for healthy soils for each local context. This goal is to be met through six primary objectives, with a seventh objective to determine and monitor the impact of the mission on the global footprint.

On the other hand, the MB argues against a silo approach where only a single indicator is tracked, as improvement in one indicator should not come at a cost of another. It accordingly proposes to use six fundamental indicators.

Specific Targets and Indicators			
Objectives	**Land Management Targets**	**Soil Health Targets**	**Six Soil Health Indicators**
Land degradation and desertification	*50% degraded land restored*	*Strong reduction in degradation and desertification*	*All 6 soil health indicators*
Soil organic carbon	*Conservation of high carbon soils and a reverse of carbon loss in croplands.*	*A switch from a 0.5 % loss per year to a 0.1-0.4% increase in SOC concen-tration in cropland soils* *30-50% reduced area of peatland losing carbon*	*Soil organic carbon stock* *Vegetation cover*
Soil sealing and net land take	*Urban recycling of land from 13 to 50%* *No net land take by 2050*	*Switch from 2.4% to no net soil sealing*	*Soil structure including soil bulk density and absence of soil sealing and erosion* *Vegetation cover*
Soil pollution	*25% of land under organic farming* *Doubling of rate of remediated sites prioritising brown field sites*	*5-25% additional land (i.e. over and above the 25% in full organic) with reduced risk from a range of pollutants*	*Presence of soil pollutants, excess nutrients and salts*
Erosion	*50% degraded land restored*	*Prevention on 30-50% of land with unsustainable erosion risk*	*Soil structure including soil bulk density and absence of soil sealing and erosion.* *Vegetation cover*
Soil structure	*50% degraded land restored*	*Reduction by 30-50% of soil with compaction*	*Soil bulk density and other measures of soil structure*
While not being a soil indicator in the strict sense, mission activities will be assessed against their impact on the health of soils outside Europe			
Global footprint	*Strengthened international cooperation; trade regulations, including carbon tax*	*20-40% reduction of current global footprint*	*Food, feed and fibre imports leading to land degradation and deforestation*

Table 1 Objectives of the mission board and the targets and indicators used to assess progress and achievement. (Source MB 2020)

In order to achieve the mission thus outlined, 4 building blocks are required, based on:

A. An ambitious cross-scale, inter and transdisciplinary R&I programme;
B. Co-creation and sharing in Living Laboratories and Lighthouses within and across farms and forest, landscape and urban settings;
C. A robust soil monitoring programme by each MS equivalent to that for other natural resources (air, water and biodiversity) using agreed methodologies including selected indicators;
D. Communication and citizen engagement embedded into all activities.

Accordingly, this report provides:

1. A discussion of the main concepts and solutions to promote Soil Health in an integrated way, based on a review of academic papers applying a "**system approach**" to the analysis of the soil health and food theme
2. A **mapping** of the most prominent measures and soil management practices against their potential contribution towards the goals identified by the MB and the associated indicators, with emphasis on those for which an impact evaluation is available.
3. A review of concepts and definitions allowing the framing, design and implement-tation of "**Light Houses (LH)"** and **"Living Labs (LL)**", and suggestions of criteria that could be adopted to devise LH and LL with a focus on soil health.

The first part of the report discusses the application of systems thinking to soil health. Pursuing the MB objectives should be based on a holistic view, acting on sectors or segments of the systems while preserving the comprehensive view and the ability to consider interactions, feed-back loops, feed-forward loops in addition to the main effects of individual actions. Complexity has several dimensions:

- Multiscale interactions between decisions made at the levels of (i) plot and field, (ii) farm, (iii) landscape, (iv) region and country, (v) global and (vi) food systems.
- Exponential growth of the number of interactions with the linear growth of the elements of the system.
- Uncertainty, arising from the incomplete knowledge of the system elements.
- Evolutionary behaviour, due to relationships that change over time in often unanticipated manners
- Different interpretation of the elements and of their interactions due to competing interests.

Against this backdrop, a number of challenges emerge in relation to the adoption of a systems approach in soil management, notably:

- Better understanding of overall soil quality, stability and resilience by disputing the decoupling between agronomics and soil science disciplines and combining the newly gained insights in individual disciplines (soil chemistry, soil physics, soil biology, pedology) where there is room for greater synergy and interdisciplinarity.
- Exploring in-depth the spatial and temporal dynamics of soil functional characteristics as the basis to derive meaningful indicators for soil functions that are sensitive to (agricultural and forest) soil management.
- Improving the agricultural production function of soil while maintaining or even improving the other soil functions, notably by combining management practices taking a whole system approach (e.g. weed depressing intercrops with minimum tillage), further fostering the concepts and practices of regenerative agriculture, sustainable and ecological intensification.
- Combining restricting instruments with supporting ones in order to promote the acceptance and the implementation of the 'right mix of soil management practices considering the specific conditions of the different local sites and farming system characteristics.

- Emphasizing and appropriately remunerating (through the CAP) the benefits of sound soil management practices (e.g. regenerative agriculture) for society at large (climate protection, flood safeguard, biodiversity etc.).
- Promoting the digitalization of agricultural management beyond the sheer goal of economic efficiency (smart exploitation of ecological processes).
- Adopting a landscape perspective to assess the impacts of soil functional dynamics to evaluate the ecosystems functions, determine the costs of soil degradation and design payment schemes for ecosystem services.
- Encouraging farmers to play a more active role as landscape stewards, caring for soils, through policies and subsidies that explicitly value ecosystem services, thus ensuring a climate resilient contribution to a sustainable food system.
- Leveraging the shift to diets with less "animal source food" to further promote agroecological concepts and practices, with benefits for both climate and human health.
- Developing research to shape a drastic reconfiguration of European agriculture, with emphasis on technology, ecology, plant-to-plant interactions, soil and plant microbiomes, bio-control of predator and parasites, etc., to be conducted with the most advanced tools of genomics, ICT applications, sensors etc.
- Raising the attention on the need to integrate agriculture at a territorial level and reduce the negative externalities associated to European imports.
- Addressing the tensions and contradictions between trade and economic interest on one side, quality of the living environment across space and over time on the other, by recognising soil-related services as a priority at different policy levels (from urban to global).
- Drawing insights from research on the interrelated nature of environmental services – more than on the inherent soil characteristics that shape them - to create an open and intersectoral dialogue with citizens on issues of global social significance.
- Strengthening the recognition and acknowledgement of the unsustainability of the current (industrial) model which secures short term economic benefits for some, while putting the burden of lost environmental services on the shoulders of the majority.

Forest, forest soil and ecosystem services deserve specific attention. According to FRA-2015 (FAO, 2016), forests represent the second largest type of use of land: 3.999 M ha or 30.6% of land (excluding Antarctica and Greenland). Forests differ greatly around the world and have a broad range of functions at the global and local scale, depending on climate, demography, social and economic contexts (HLPE, 2017).

Forests display a broad range of interconnected functions and services contributing to the production of wood and food, the provision of energy and recreational activities, the preservation of biodiversity and fundamental ecosystem functions. As regards climate mitigation function, the subject of carbon sequestration is open to debate. While a typically mature forest is most likely neutral, the issue of first-generation energy production by burning woody biomass is more delicate. In the latter case, a zero-balance between carbon captured by growing trees and carbon released can never be reached due to energy employed or lost in the conversion; however, a "substitution" concept can be invoked, meaning that the alternative "fossil" energy would be significantly more negative in terms of net CO2 emissions.

The importance of forests for the preservation of fundamental ecosystem functionality has been remarked by Steffen *et al.* (2015) who proposed "Land-system Change" as one of the planetary boundaries, with an indicator being the area of forested land as % of potential forest in different biomes.

In addition, the role in ecosystems preservation connects forest management with the widespread debate on possible "payment for ecosystem services" (PES). There is a need for research that enable on the one hand an evaluation of the economic value of services and on the other hand the costs (better, cost opportunities) of different management decisions (EEA, 2016). The Ministerial Conference on the Protection of Forest in Europe has agreed upon a definition of Sustainable Forest Management (SFM) – taking a broader view compared to the concept of Ecosystem Based Management of Forest (EBM) which focuses on the preservation of biodiversity, the functionality of ecosystems and the provision of ecosystem services (EEA 2016). Forest Management Plans are an essential component of SFM and are being gradually applied around the world. Europe is leading with 94% of forests managed according to a formal plan (FAO, 2016). At the local level voluntary, most common private certification schemes of sustainable forest management (SFM) are FSC (Forest Stewardship Council, supported by environmental NGOs) and PEFC (Programme for the Endorsement of Forest Certification, with a strong base in forest owners).

The main objective of any management decision and any forest operation should be to avoid soil disturbances or make their effect as transitory as possible. In the foreseeable future, a significant threat to forest ecosystems and forest soils in particular, is represented by the increasing interest of the wood industry and the renewable energy industry in trees as a renewable raw material in the context of the Bioeconomy.

A compromise (or a priority order) between competing objectives must be achieved, albeit at a regional level, between:

a) maximisation of the role of forests as carbon sinks (both above and below ground);
b) maximisation of biomass production;
c) maximisation of biodiversity preservation.

The main risk of having the maximisation of biomass as a leading priority, especially for the production of energy, is that of a progressive impoverishment of soil fertility leading to a decay of long-term forest health. Increased removals of harvest residues lead inevitably to a loss of nutrients and fertility. A public debate should inform decisions and a widespread knowledge should inform it, as it often appears more ideological than rational.

Across all the above challenges, the need for a systems approach is evident. When it comes to research, many publications focus on specific management measures and practices, but they tend not to set the intervention within a systems context, hence emergent behaviours of combining interventions do not come through such rather linear exercises. This is partly due to the flaws of the environmental accounting systems which lack consistent, uniform statistics and adopt inadequate approaches to the monitoring and evaluation of policy impacts.

Adopting a system approach in fact amounts precisely to focusing on the interrelations between the system components, not only on the individual behaviour of each of them. Mapping these interrelations is what the next chapter is about.

The ultimate objective of the **second part of the report** is to indicate (to map) which practices can contribute to which objective(s). It draws from current literature to show how indicators map to the six primary mission board objectives and how farm practices, or interventions, map to indicators. It also highlights the current linearity of measures and the need for greater integration and systems thinking through for example the whole form or landscape approach.

For both the objectives and the indicators the starting point of the mapping is the MB paper (6 objectives + 1; 6 indicators). The table below provides expert judgement on the direction of change (positive/ improving, negative/worsening, or variable effect) as well as on the expected intensity of the impact, e.g. positive +, strongly positive ++).

	MB Objectives						
Soil health indicators	Reduced_ soil_ degradation	Increased _ SOC	No_net soil_ sealing	Reduced_ soil_ pollution	Prevented _erosion	Improved_ soil_ structure	Reduced_ food_ footprint
Soil_contaminants				++			
Vegetation_cover	+				+		
Organic_matter_ content	++				+		
Soil structure						++	
Soil_biodiversity		+				+	
Soil_nutrients		±					
Soil_sealing			++				
Degraded_soils	++				+		

Table 2 Mapping MB soil health indicators to MB soil health objectives.
Source: JRC (2010), Maskell et al (2019)

However, in order to better reflect the complexity of the system, additional, "indirect" effects and the corresponding indicators are also considered and illustrated in the report, namely (i) other environmental effects such as water quality, water retention etc. and (ii) economic performance effects such as yields and costs.

For what concerns the practices, two categories are considered, namely (i) Basic soil management practices, which are primarily aimed at improving soil health and are commonly adopted in farm practice (figure below) and (ii) Other relevant management practices, which are either adopted under special conditions or primarily addressing other environmental problems/benefits (also shown in the body of the report). In the map below and in all the figures of this report, the size of the node reflects the number of connections associated with the corresponding item while the intensity of the effect is represented by the thickness of connecting lines.

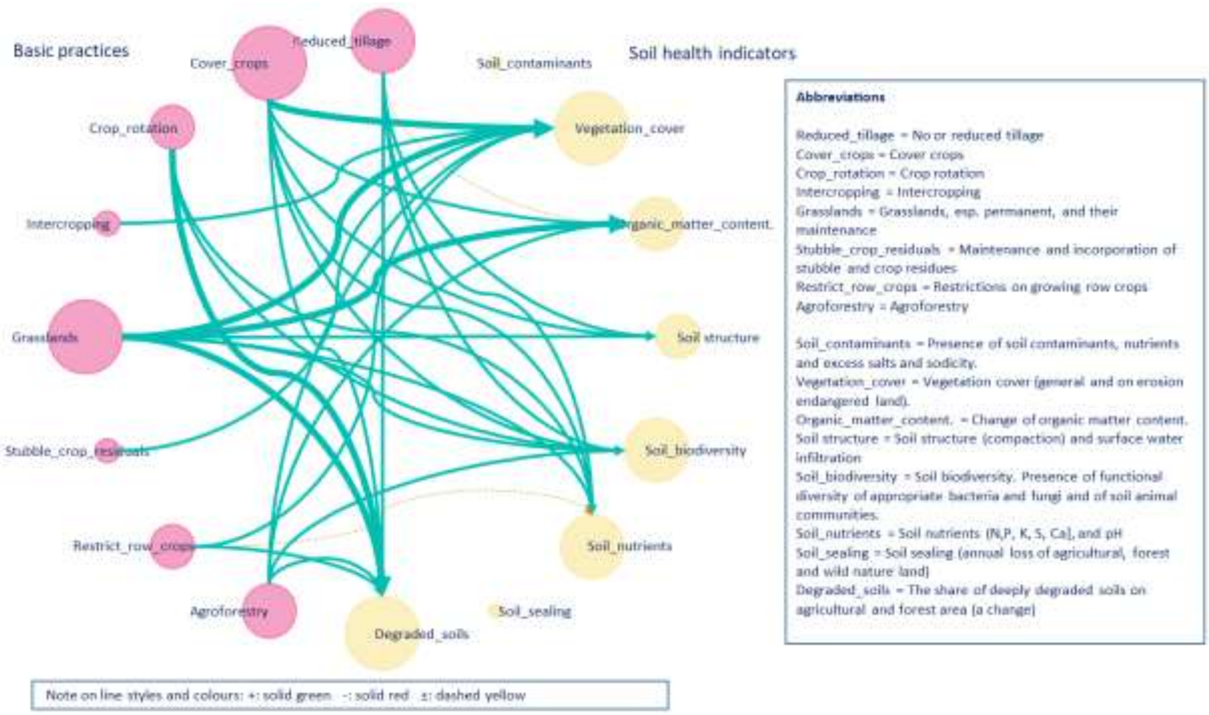

Figure 1 Mapping basic practices to soil health indicators.
Source: own elaboration based on Table 9

The mapping thus provides a wealth of indications on the relative importance of practices, beyond their immediate contribution to individual indicators: which practices have an impact on the higher number of indicators, which indicators can be influenced by the greater variety of practices.

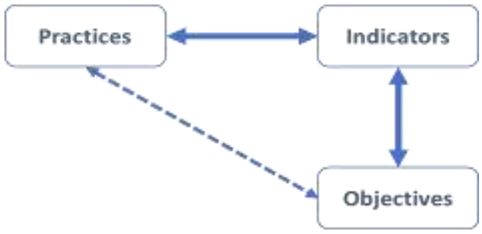

Figure 2 Mapping exercise structure

As regards which combinations of practices would seem more effective in achieving the ultimate objectives (the dotted arrow in the figure above) the multiplicity and complexity of the interrelations makes it impossible to represent the latter in a straightforward manner: the visual inspection of the overall map below can however help in identifying prominent pathways, to be further explored in targeted analyses.

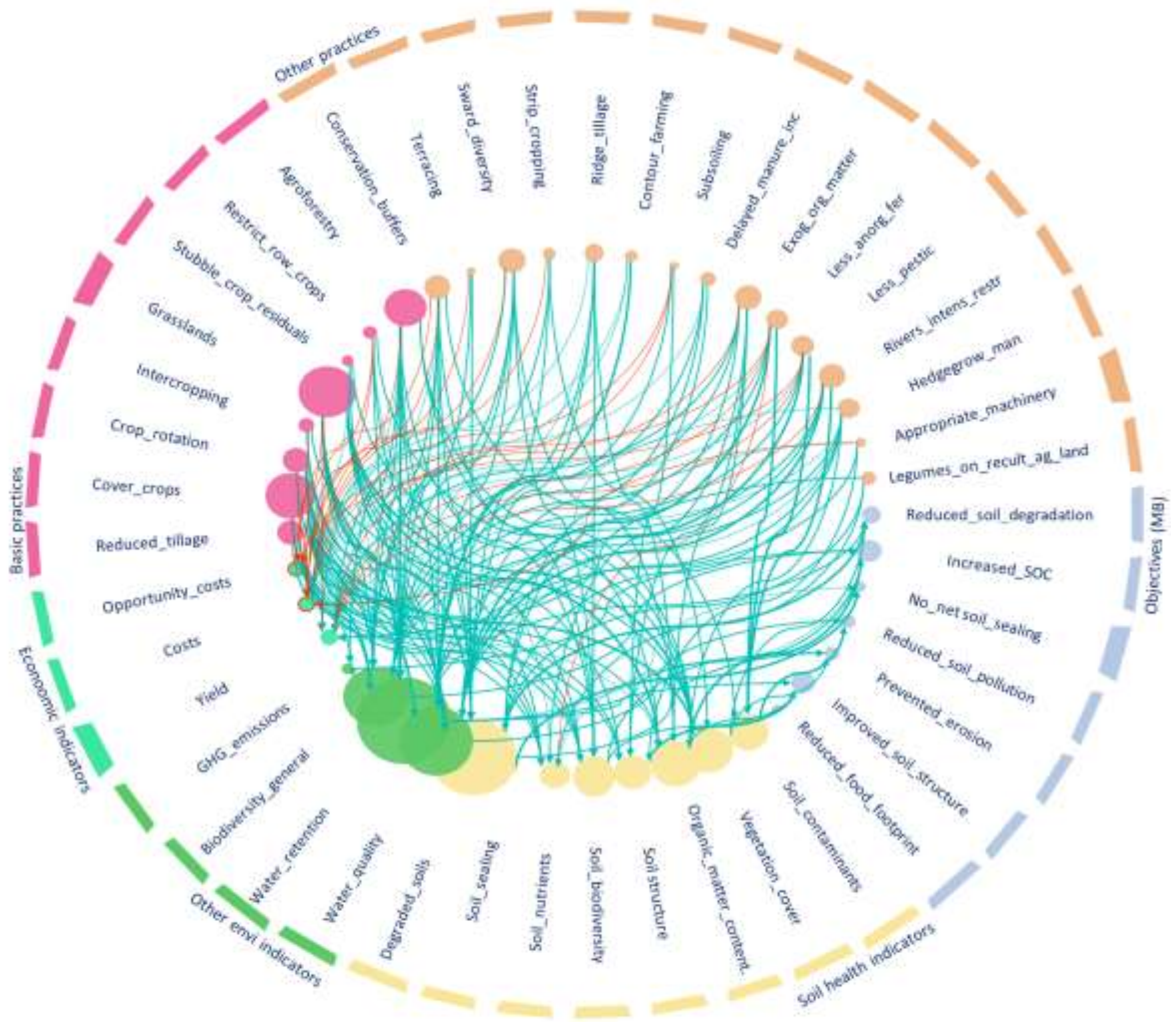

Figure 3 Overall map of practices and effects.

At a more aggregated level, the figure below illustrates the contribution that different farming systems (organic farming, integrated crop management system, conservation agriculture) can provide to the attainment of the MB objectives.

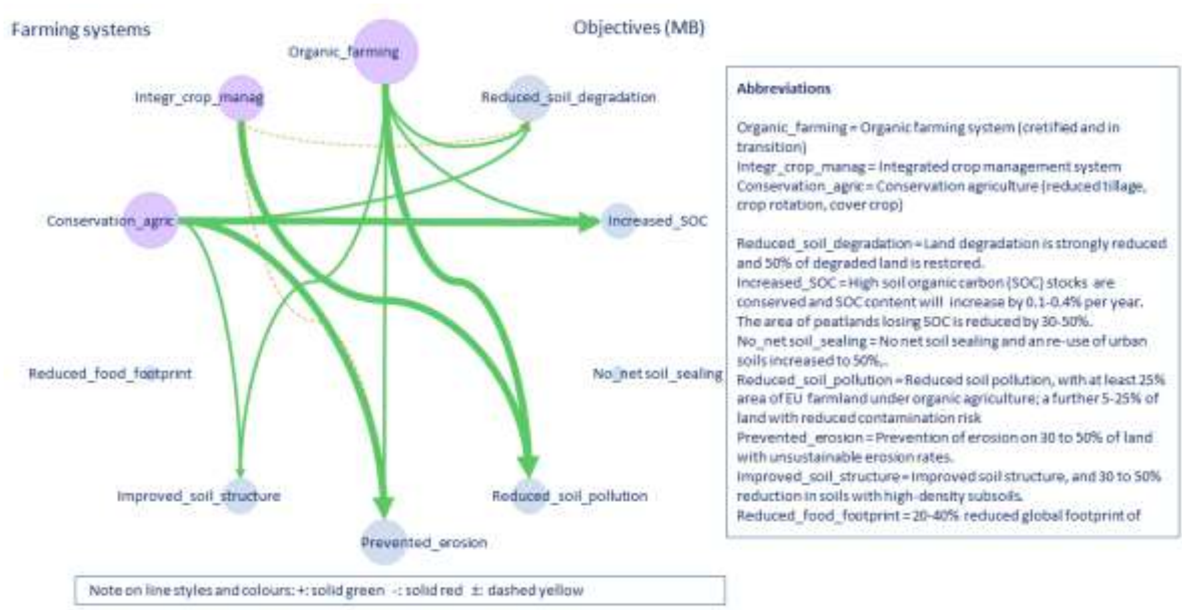

Figure 4 Mapping farming systems to mission objectives.
Source own elaboration based on Table 17

This overview of the linkages between management practices, soil indicators and mission board objectives provides support for building interdisciplinary and transdisciplinary approaches, one mechanism for which is through the use of Living Labs, reviewed in the third chapter.

The third part of the report reviews and discusses definitions and concepts associated to Living Labs (LL) and Lighthouse (LH) projects as they appear in the available literature. It then illustrates practical examples of LL and LH in the area of soil health, and finally proposes a set of criteria to guide the design and implementation of future LL and LH to be possibly activated by the Mission.

There is no standard, commonly agreed definition of LL. It is however generally understood that the LL approach features a user-centred, real-world research environment in which not only science, business and organizations jointly carry out research and development, but above all the users themselves take an active role within the innovation processes.

Similarly, despite the absence of a standard definition, an LH project can be construed as a short-term, well defined project that serves as a model for other similar projects. In a broader context, LH projects are used to develop the scientific basis for multidisciplinary transition and innovation research and an accompanying communication program.

In the area of arable and livestock farming, the FAB-Farmers Interreg project is a Living Lab that focuses on soil health and food, and aims at the acceleration of the adoption and implementation of functional agrobiodiversity (FAB), including reduced tillage, mixed crops rotation, cover crops, organic matter input, manure quality, agroforestry, hedgerow management, field margin management, the reduction in the use of plant protection products, and semi-natural landscape elements. The emerging concept of 'Sustainability Living Labs' is particularly interesting as it is led by sustainability criteria and aims to contribute to global and universally applicable patterns of production and consumption.

In the same area, the Lighthouse Farm Network brings together exemplary farms from around the world that have found radical solutions to address sustainability challenges". Its main goals are (i) to provide opportunities for engagement and collaboration with farmers, stakeholders, industry and policymakers, (ii) to facilitate shared learning between contrasting lighthouse systems, and (iii) to provide a platform to anchor international collaboration.

In the forest area, an interesting example of a Lighthouse project can be found in the Loewenberger Land, under the responsibility of the University for Sustainable Development in Eberswalde. It is intended as a showcase and training venue to demonstrate how a complex agroforestry system to counteract compaction, evaporation, impoverishment, loss and sealing of soil can be structured.

A further example can be found in the area of the urban and peri-urban fringe. The "Frisch vom Dach" lighthouse project (Berlin) sets out to build the world's largest aquaponic roof farm on the roof of the Berliner Malzfabrik in order to practice sustainable agriculture and fish breeding all year round. It is known to have inspired many of the urban farming and gardening projects developed in the past decade.

This review of concepts and of practical experiences suggests a set of basic criteria for the development and operation of Living Labs:

Objective:
- To support co-creative, human-centric and user-driven research, development and innovation in order to better cater for people's needs.

Structure:
- Established as a network
- Include multiple stakeholders
- Stage a real-life research environment
- Have a well-defined mission to tackle innovation problems

Activities
- Co-creation: co-design by users and producers
- Exploration: discovering emerging usages, behaviours and market opportunities
- Experimentation: implementing live scenarios within communities of users
- Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria

Ambition:
- Open innovation oriented: a governance based on facilitating innovation by actively involving people in the ecosystem to search for value, even before it is identified as valuable.
- A challenging and interdisciplinary program: at the heart of the future Living Labs is a program of challenging, concrete projects that enable a joint learning process and bond people from different backgrounds.
- Jointly developing sustainable platforms: Continuous development of open, multipurpose democratised platforms (a mash-up of data, services and products) to enable a diversity of propositions.
- Co-learning in an ambitious ecosystem: An ecosystem of ambitious people who understand the challenges and are willing to contribute with the prospect of being able to benefit from the innovation.
- Creating a social and physical 'meeting place': An interactive place where designers, developers, entrepreneurs and researchers meet and co-create real solutions for real people in real-life settings.
- Boosting prosperity and welfare in the region: A co-creative, experimental environment that contributes to the welfare and well-being in the region by creating new businesses (jobs) and a vibrant economy.

1. Systems Approach

1.1. Introduction

Is the Mission target of achieving 75% of European soils in healthy state by 2030 too ambitious? Our feeling is that it is not. A mission has to be ambitious; the "man on the moon" was ambitious; the EGD[1] target of achieving carbon neutrality in Europe by 2050 is even more ambitious. Visions must be ambitious. If a healthy soil is a precondition for our life and for the life of the planet, then it is not a matter of ambition: it is a necessity.

Echoing the well-known "think globally, act locally" exhortation, action should be based on a holistic view, on systems thinking, acting on sectors or segments of the systems while preserving the comprehensive view and the ability to consider interactions, feed-back loops, feed-forward loops in addition to the main effects of individual actions. Of course, this is easier said than done, as complexity brings along a range of challenges.

- Multiscale interactions. While decisions on the management of soils are taken for each field individually by the farmer, its impact on soil functions and ecosystem services appears at the landscape scale. Farmers' decision making on soil management is subject to a family of external driving forces including regional value chains, national policies, international trade agreements and global climatic changes.
- Exponential (or, rather, factorial) growth of the number of interactions with the linear growth of the elements of the system. Even in the hypothesis of a mathematical modelling of complex systems (clearly possible only in rather limited circumstances), the treatment of information would soon become very hard to manage.
- Uncertainty. Incomplete knowledge of the elements of systems makes the outputs of modelling erratic with even minimal variations in the initial parameters so that their long-term behaviour is difficult to predict with accuracy even in physical systems, let alone in areas where physical elements interact with biological and social ones.
- Evolutionary behaviour, due to relationships that change over time in an often unanticipated manner.
- Different interpretation of the elements and of their interactions due to competing interests, different ideas on the representation of facts and goals (*Weltanschauung*).

Soil, soil health and the connected environmental and socio-economic services are no exception: a systems approach is needed to address complex soil-related issues, taking into account above and below ground interaction, and to govern activities for achieving soil health across governance levels and scales (plot and field; farm; landscape, regional and country, global, food system).

We here provide a few suggestions and try to corroborate them with examples.

1. Adopt a transdisciplinary approach also to problems that might appear just technical. The tendency of framing problems in just technical terms that call for technological solutions has brought to a number of dead ends, the most obvious one being the genetically modified organisms (GMOs), when the assumed superiority to conventional cultivars was assumed as a sufficient reason for widespread adoption, failing to appreciate the links with human fear of "un-natural" food, with intellectual property issues, with a widespread mistrust of multinational companies, with the clear down-playing of possible collateral damage, etc. The "soft" sciences and the involvement of society should always play a prominent role.

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1 European Green Deal: https://ec.europa.eu/info/publications/communication-european-green-deal_en

2. Avoid being captured by conventional thinking: think out of the box, defy given truths, challenge common wisdom. One area in which the status quo should be challenged is the breadth of rights attached to private property or possession of land. This means circumscribing the rights of owners vs the rights of society to fundamental environmental services that should neither be privatised nor hampered. This is already evident with forest land, at least in many European countries, where hydrogeological functions, landscape preservation, rights of public access coexist and usually override the rights of forest owners to economic exploitation. This is not so well recognised in the agricultural domain in urban contexts. The monetisation of services and damages is not the ultimate solution, as positive behaviours induced by subsidies last as long as the subsidies, and negative behaviours sanctioned by taxation (e.g. carbon emissions) are treated as mere additional cost factors.
3. Explore and exploit synergies rather than trade-offs. Trade-off analysis is often focused on simple alternatives compared on a single or a limited set of criteria. A recurrent example is the comparison of organic farming with conventional farming based on single crop productivity, whereas organic production may get higher market prices, reduce the cost of inputs, help restore biodiversity, minimise pollution of surface and ground water, increase carbon storage in soils, etc.
4. Robustness/resilience vs optimisation. Searching for the optimal combination of factors in complex systems does not necessarily imply robustness of systems under suboptimal situations; rather, the design of systems that perform "satisfactorily" under a range of possible conditions and are able to absorb shocks and return to the previous state under perturbation is deemed a better strategy in times of uncertainty. This is especially so under the present uncertainty about climate change and the real implementation and efficacy of mitigation efforts.
5. Avoid the risk of "analysis-paralysis". As for robustness/resilience, decision making processes must not be captured by the expectation of perfect information. When the approach to problems has been reasonably broad and comprehensive, imperfect information must be accepted. The ever-increasing demand for more data and more information to undertake any change in consolidated systems is often a strategy adopted by incumbents to delay or avoid the loss of dominance positions.

1.2. Systems at the different scales

In the following we consider the different scales outlined in the Mission Board interim document "Caring for soil is caring for life" (Plot and field, Farm, Landscape, Region and country, Global, Food system) as a reference and explore the connections/dependencies vertically with the provisioning of ecosystem services[2] in order to make the links explicit and show the importance of an integrated approach vs a fragmentary, reductionist approach.

A systematic treatment of the subject based on a comprehensive literature review would have been beyond the scope of the present work and therefore we have focused the discussion on important highlight papers/documents that synthesise the state-of-the-art and may provide either useful hints or examples applicable in a range of similar situations.

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2 a) Producing adequate quantities of nutritious and safe food, feed, fibre and other biomass for industries; b) Regulating and storing water and recharging aquifers, purifying polluted water, and reducing the impact of droughts and floods, thereby, helping adaptation to climate change; c) Capturing carbon from the atmosphere and reducing emission of greenhouse gases from soils, thereby, contributing to climate mitigation; d) Nutrient cycling supporting crop productivity and reducing contamination; e) Preserving and protecting biodiversity by preserving habitats both above and within the soil; f) Supporting the quality of our landscapes and greening of our towns and cities.

1.2.1. Plot and field scale – soils as complex systems and the concept of soil functions

Soils are among the most complex systems at the interface between the geosphere, atmosphere, hydrosphere and biosphere. A multitude of biological, chemical and physical processes interact within a heterogeneously structured environment across many different hierarchical scales from single soil pores to the distribution of soil types in the landscape. As a consequence, recent soil science is organized in a number of largely independent sub-disciplines (soil chemistry, soil physics, soil biology, pedology). Significant progress has been achieved within these disciplines, mainly driven by the development of new analytical techniques: Soil became transparent by using tomographic methods so that it is possible to quantify soil structural properties, to analyse water dynamics in three dimensions or to visualize growing plant roots. Moreover, today it is possible to analyse the microbial genetic diversity and the chemical composition of soils in great detail and at high spatial resolution. However, there remains an intermediate scale measurement gap (Field scale) between measurements at the sample scale mostly made in laboratories and those obtained from remote sensing that tend to cover areas in excess of 1km. Despite these developments, however, it remains a challenge to combine the newly gained insights for a better understanding of overall soil quality, stability and resilience. Instead, soil degradation is ongoing irrespective of the scientific achievements related to soil process understanding. A decoupling of the agronomic and soil science disciplines also led to the trend that agriculture was seen as part of the problem but not part of the solution.

The debate on soil conservation lead to the identification of the most important soil threats, as soil degradation processes are primarily associated with agriculture (erosion, compaction, salinization, organic matter loss, biodiversity decline), industry (contamination), urbanisation and infrastructure development (sealing)[3]. (Failed) attempts to implement soil conservation policies addressing these threats focused on restricting rather than supporting instruments with the predictable effect that the acceptance of these political efforts remained limited[4].

In the last decade, focus has then shifted from soil threats to soil functions to better articulate the fundamental role soils play for societal challenges. The concept was also taken up in the thematic strategy for soil protection[5] and it fully acknowledges the multifunctionality of soils and its interaction with any land use and management action upon it[6,7]. The performance of soils regarding these functions depends on inherent soil properties (e.g., texture, depth, mineralogy, and horizon sequence), geo-biophysical site conditions (e.g., relief, climate, and altitude), their management history, and actual soil processes as affected by soil management practices.

Soil functions are the linkage from soil systems' processes to the valuation of performance or their services in the context of sustainable development. To assess the interaction between soil management and soil functions, there is a need to identify soil functional characteristics that integrate systemic knowledge about the complex, non-linear interactions between soil components and processes on various temporal and spatial scales on the one hand, and to link them to soil management practices, especially combinations of practices, on the other hand. Soil functional characteristics emerge from the interactions between soil components (e.g., minerals, roots, and organisms) and soil processes (e.g., physical, chemical and biological processes). They are sensitive to soil management and

3 European Commission (EC). "Towards a Thematic Strategy for Soil Protection" (COM(2002)179)

4 Glaesner N, Helming K, De Vries W. 2014. Do current European policies prevent soil threats and support soil functions? Sustainability 6, 12, 9538-9563

5 European Commission (EC). "Thematic Strategy for Soil Protection" (COM(2006)231)

6 Schulte, RPO, Creamer, RE, Donnellan, T, Farrelly, N, Fealy, R, O'Donoghue, C, O'hUallachain, D. 2014. Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. Environmental Science & Policy 38: 45-58.

7 Helming K, Daedlow K, Paul C, Techen A, Bartke S, Bartkowski B, Kaiser DB, Wollschläger U, Vogel HJ. 2018. Managing soil functions for a sustainable bioeconomy – Assessment framework and state of the art. Land Degradation & Development 29:3112-3126.

may change at a time scale of days to months. Examples are e.g., water capacity, aggregate stability, macropores, organic matter, and functional group diversity. The typical range of such functional characteristics depends on the soil type and the inherent soil properties that are considered to be stable at the time scale of decades[8]. They in turn influence state variables (e.g., water content, biological activity and temperature) that change very quickly within days. The challenge is an in-depth exploration of the spatial and temporal dynamics of soil functional characteristics as the basis to derive meaningful indicators for soil functions that are sensitive to the key pressure of (agricultural) soil management[9].

1.2.2. Farming system scale – regenerative agriculture and the use of emerging digital technologies

In agricultural production systems, the challenge is to improve the production function of the soil while maintaining or even improving the other soil functions. Here, the concept of conservation agriculture has been promoted for decades. Permanent soil coverage, reduced (or zero) tillage and diversified crop rotations are among the key building blocks for this concept for cultivated land. The exact implementation of these components is subject to local site-specific conditions and farming system characteristics. One-size-fits-all solutions are not possible and the implementation requires agronomic experience and knowledge about the local soil systems behaviour. In addition, the implementation may be associated with severe environmental trade-offs, e.g. minimum tillage is usually associated with the extensive use of herbicides, in particular glyphosate products.

Soil improving management practices need to be implemented in combination. For example, the use of weed depressing intercrops and/or cover crops that go along with minimum tillage. This is acknowledged by the more recent concept of regenerative agriculture, which actually places the improvement of soil health at the centre of the cropping system to save external resources and make the farming system resilient to climate change. It can be seen as an attempt to implement the concept of sustainable intensification[10] and in particular ecological intensification[11], which claims to stabilize and increase biomass production while minimizing natural resource use, in particular the use of water, land, energy, carbon, labour, and external production factors such as fertilizers and pesticides. The approach puts emphasis on intensifying ecological interactions at the soil-root interface to better exploit the inherent capacity of the microbiome to turn organic substances into plant accessible nutrients, to improve water accessibility to roots and to improve habitat conditions for natural antagonists of pests.

Rapidly emerging knowledge about the functional role of processes in the microbiome in combination with established best practices such as conservation tillage, improved crop rotations, spatial diversification of cropping patterns are promising developments on the way to realising ecological intensification[12]. Here, innovations related to digitalization of

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8 Vogel HJ, Bartke S, Daedlow K, Helming K, Kögel-Knabner I, Lang B, Rabot E, Russell D, Stößel B, Weller U, Wiesmeier M, Wollschläger U. 2018. A systemic approach for modeling soil functions. SOIL 4:83–92.

9 Bünemann, EK, Bongiorno, G, Bai, Z, Creamer, RE, De Deyn, G, de Goede, R, Fleskens, L, Geisen, V, Kuyper, TW, Mäder, P, Pulemann, M, Sukkel, W, van Groeningen, JW, Brussard, L. 2018. Soil quality – a critical review. Soil Biology and Biochemistry 120:105-125.

10 Garnett, T, Appleby, MC, Balmford, A, Bateman, IJ, Benton, TG, Bloomer, P, Burlingame, B, Dawkins, M, Dolan, L, Fraser, D, Herrero, M, Hoffmann, I, Smith, P, Thornton, PK, Toulmin, C, Vermeulen, SJ, Godfray, HCJ. 2013. Sustainable Intensification in Agriculture: Premises and Policies. Science 341: 33-34.

11 2014 Tittonell, P. 2014. Ecological intensification of agriculture—sustainable by nature. Current Opinion in Environmental Sustainability 8: 53-61.

12 Techen, A. Helming, K., Brüggemann, N., Veldkamp, E., Reinhold-Hurek, B.,; Lorenz, M., Bartke, S., Heinrich, U., Amelung, W., Augustin, K., Boy, J., Corre, M., Duttman, R., Gebbers, R., Gentsch, N., Grosch, R., Guggenberger, G., Kern, J., Kiese, R.,; Kuhwald, M., Leinweber, P., Schloter, M.,

agricultural management are promising provided that their use is dedicated to the smart exploitation of ecological processes and not only to a further improvement of economic efficiency. Modern sensors allowing real-time and onsite monitoring of dynamic soil and plant conditions provide data that can be transferred into decision support on high precision applications of fertilizers and water as well as to mechanical solutions for weed control. In addition, the use of autonomous machinery (robots) and swarm technologies may in the future replace large and heavy machines thereby avoiding soil compaction and allowing for field sizes to become smaller again and better reflect landscape features, minimize erosion and improve micro-climatic controls and biodiversity habitats.

In any case, improvement in soil processes and dynamics can be slow as are the outcomes of soil improving management practices. Therefore, regenerative agriculture is an investment in the future rather than a short-term solution to economic wellbeing. Farmers need a financial buffer to survive through this transition period. At the same time, however, a healthy soil fulfils a wide range of functions and ecosystem services that benefit society as a whole. Climate protection, flood protection, habitat for biodiversity are just a few of them. The remuneration of these public services should therefore be given more prominent consideration in the revision of the Common Agricultural Policy and it also offers opportunities for market-based solutions. Consumers, policy-makers and practitioners thus interact in the endeavour to improve soil health for the benefit of society.

1.2.3. Landscape scale – natural capital and soil-based ecosystem services

While decisions on soil management are taken at the farm level thereby inserting pressures on soil functions within these fields, it is the landscape where the impacts of such soil functional dynamics become apparent. Water quality, water balance and flood control, soil erosion, cooling, biodiversity, and cultural values such as aesthetics and recreational services are features of the landscape that are fundamentally affected by soil management and behaviour. Here, the concept of ecosystem services comes into play. It was developed to express the value of nature to human societies. By linking soil functions to ecosystem services, the role of soil services for human wellbeing can thereby be valued and the costs of soil degradation be determined. Ecosystem services are defined as the contributions of ecosystem structure and function (in combination with other inputs) to human well-being. The concept is well established in both research and policy making. Since the first conceptual basis was laid for analysing ecosystem services in relation to soils[13], the subject is discussed in relation to soils as natural capital, landscape management, institutional economics, sustainable development goals and sustainability assessments.

Wiesmeier, M., Winkelmann, T., Vogel, H.J. 2020. Soil research challenges in response to emerging agricultural soil management practices. Advances in Agronomy 161:179-240

13 Adhikari, K, Hartemink, AE. 2016. Linking soils to ecosystem services — A global review. Geoderma 262: 101-111.

Figure 5 The relationship between soil functions and ecosystem services. (Adapted from Adhikari and Hartmink, 2016)[13]

The implementation of the ecosystem services concept to assess the role of soils therein requires a standardised approach to indicator development. The Common International Classification of Ecosystem Services (CICES) of the European Environment Agency is a good basis for this if adapted to the specific requirements related to soil services[14]. The contribution of soils to ecosystem services and thus human wellbeing appears best at the landscape scale because this is the scale where societal demands are confronted with land use supply of ecosystem services and where social, economic and environmental aspects of soil management interfere. The prominent role of the landscape has been acknowledged by the Horizon Europe Mission Board on Soil Health and Food, who in their interim report 'Caring for Soils is Caring for Life' complement the soil functions concept with a landscape perspective[15].

The Concept of ecosystem services is anthroprocentric and originally emerged from economic theory to assess the economic value of ecosystems as a basis for (policy) decision making. This natural capital approach attempts to internalise the public good character of the ecosystem into economic accounting and thereby into micro-economic and macro-economic decision making. Substantial international effort is being undertaken to develop a global accounting framework to complement gross domestic product indicators (GDP) through the United Nations System of Environmental and Economic Accounts (SEEA). A Natural Capital approach may provide an important basis for the design of payment schemes for ecosystem services, an approach that actually would enable the remuneration of farmers for their contribution to those public services. Research is actively searching for solutions to put such accounting and payment schemes into practice at different governance levels[16]. If policies and subsidies in the agricultural sector could adopt the payments of ecosystem services concept, farmers could play a more active role as landscape managers in support of soil health and ecosystem services, thereby ensuring a climate resilient contribution to a sustainable food system.

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14 Paul, C; Kuhn, K; Steinhoff-Knopp, B; Weißhuhn, P; Helming, K. 2020. Towards a standardisation of soil-related ecosystem service assessments. Eur. J. Soil Sci. 2020, accepted article doi:10.1111/EJSS.13022

15 Mission Board Soil Health and Food. 2020. Caring for Soil is Caring for Life.

16 Robinson, D.A., Fraser, I., Dominati, E.J., Davidsdottir, B., Jonsson, .O.G., Jones, L., Jones, S.B., Tuller, M., Lebron, I., Bristow, K.L., Souza, D.M., Banwart, S. & Clothier, B.E. 2014. On the Value of Soil Resources in the Context of Natural Capital and Ecosystem Service Delivery. Soil Science Society of America Journal, 78, 685-700.

1.3. Region and country (Regional & national food systems)

Ten years for agroecology – A European Agriculture based on agroecological principles and practices in 2050[17]

Agroecology as the founding paradigm of a "new" agriculture, in contrast to the widespread "industrial" model, and is a typically systemic approach as it is based on the exploitation of positive synergies between the components of the agroecosystems instead of focusing on the reductionist approach based on the application of exogenous inputs that artificially create favourable conditions for a single main crop. It builds upon Tittonells' concept of ecological intensification[11].

In addition to that, Agroecology, especially in other parts of the world, has a strong social component as it aims at empowering farmers as actors in the food chain rather than providers of cheap biomass for industrial transformation at the mercy of downstream players.

Agroecology simultaneously aims at the health of the environment (soil, air, water) by minimising the application of fertilisers, at the preservation of biodiversity (pollinators, insect predators, hyperparasites) by avoiding the spread of plant protection products, at the mitigation of climate changes, at the production of healthy food for healthy diets.

Although kept for decades on the fringes of conventional science for conventional agriculture, agroecology is gaining traction worldwide thanks, in particular, to the efforts of FAO that dedicated two world conferences and numerous regional conferences and set up an Agroecology Knowledge Hub[18]. More recently, the European Commission openly endorsed Agroecology as a preferred, albeit non-exclusive, approach to agriculture in the "*Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system*" (COM/2020/381 final).

The IDDRI Study "Une Europe agroécologique en 2050: une agriculture multifonctionnelle pour une alimentation saine - Enseignements d'une modélisation du système alimentaire européen" reports the outcomes of a modelling exercise (carried out in the "Ten Years for Agroecology in Europe" project started in 2104) applied to the European agricultural system aimed at reducing the negative impacts of current agricultural practices on health, climate, biodiversity, while ensuring sufficient production to feed Europeans with healthy diets and avoiding the export of negative impacts of our food systems to other continents.

A reduction of productivity of agroecological systems with respect to conventional models may be expected, based on an analogy with organic farming, at least if calculated on a "single crop" basis, although productivity calculations depend on the way they are carried out, as clarified in a report of 2016 by IPES-Food[19].

The main driver of change would be represented by a shift to diets with less "Animal Source Food" to within the amounts recommended by the World Health Organisation and most national dietary recommendations. As most of the agricultural biomass is currently devoted to livestock production, a significant share of the land dedicated to the production of animal feed could be devoted to human food, thus compensating lower (if any) productivity and achieving the goal of producing adequate quantities of nutritious and safe food and feed. Fibre and other biomass for the bioindustry in adequate amounts can be secured by forestry (sustainably practiced) and improved circularity along the agri-food chains. A sector that would be downsized in the TYFA model is the production of biofuels; it must be

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17 Poux X, Aubert P-M. 2018. Une Europe agroécologique en 2050: une agriculture multifonctionnelle pour une alimentation saine. Enseignements d'une modélisation du système alimentaire européen, Iddri-AScA, Study N°09/18, Paris, France, 78 p

18 http://www.fao.org/agroecology/home/en/

19 IPES-Food. 2016. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems. http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

acknowledged, however, that the very efficiency of energy production from agricultural crops is being questioned also outside of an agroecological context. Fuel crops, be it maize or canola, are typical of a uniform, large scale monocrop agriculture, where typically energy return on investment is low.

Contrary to the "common wisdom" that would recommend a reduction of ruminants, as the main culprits of methane emissions, systems modelling recommends giving them a priority over monogastrics, as ruminants can feed on grass and thus contribute to the preservation of pasturelands, relevant carbon sinks and precious natural ecosystems, without competing with food production. Manure, in turn, would represent a significant source of nutrients for agricultural fields in the absence of external application of synthetic fertilisers. The fertility would also be improved by nitrogen fixing species in conjunction or in alternation with food crops. The reduction in the use of fertilisers, also the target of the Farm to Fork Strategy[20], would be an obvious consequence of the application of agroecological practices.

The reconstruction of complex ecosystems would be obtained also by the reduction of uniformity at the field, farm and landscape scales: trees, hedges, fallows, humid zones. Richer and more varied landscapes would gradually evolve.

Companion crops, green mulching, reduced or no tilling, incorporation of residues, would contribute to increasing the soil organic carbon content, with benefits for climate change mitigation, improved fertility, the recreation of vital biological communities and rich biomes, reduced erosion and a more efficient action of soils in the water cycle. Complex ecosystems would sustain communities of predators and hyperparasites of crop pests reducing their impact in the absence of synthetic pesticides.

A self-sufficient European food system would also minimise the negative impacts provoked by the production of European imports. It has been calculated that soy imports alone from South America correspond to around 35 million hectares in areas where agriculture is still expanding into forests or grasslands with huge negative consequences for climate, biodiversity and, quite often, for the welfare and even the survival of native populations.

The TYFA modelling study has the merit of showing the feasibility and the coherence of a European agriculture based on agroecological principles and practices. Changes in behaviours have been shown to be achievable during the COVID-19 confinement experiences; even a significant reduction of animal proteins in the diets is within reach considering the joint benefits for climate and one's health. Agriculture would be more integrated at the territorial level, with a reduction of international trade and increased self-sufficiency, which have proved to be at least a component of resilience during the pandemics. Exports in some sectors would suffer, of course (e.g. pork meat to China, poultry to the Middle East) but high value products (e.g. cheese, wine) could still be produced and offered on the international market.

A recalcitrant position is to be expected from the agricultural inputs industry, pesticides and fertilisers *in primis* (already perceived in the public debate), but other sectors could find new pathways of development, such as the seed industry (with breeding priorities shifting from responsiveness to fertilisers to rusticity) or the machinery industry, with new equipment designed for intercropping, management of vegetation (e.g. green mulching), etc.

Research would need a drastic reconfiguration, with emphasis on ecology, plant-to-plant interactions, soil and plant microbiomes, bio-control of predator and parasites, etc.: advanced research conducted with the most advanced tools of genomics, ICT applications, sensors

20 A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system (COM(2020) 381 final)

1.4. Global (Impact outside Europe)

Trade treatises vs "common goods"[21]

A holistic, cross-sectoral approach to policies is necessary if environment, health, climate, sustainability are to become key elements of internationally coordinated actions. Many international agreements (e.g. the Paris Accord on climate of 2015) have been signed, albeit in a period in which multilateralism was not as under fire as it is today.

The principles and the directions have been clarified also with the support of an environmentally conscious social movement in many parts of the world. However, when rules and policies are disputed the reasons of free trade emerge as the strongest. Legally binding international treatises drawn under the WTO have a single clear objective: creating a favourable environment for trade, investments, access to markets by removing any legal, financial, fiscal, regulatory barrier to the free exchange of goods, services and capitals and protecting private interests from the jurisdiction of nationally determined priorities.

In the food systems this has clearly favoured the growth of industrial approaches in primary production (farming), farming inputs provisioning, commodity trading, processing and retailing. The principle of competition based on comparative advantages, specialisation, economies of scale, has developed alongside the green revolution that certainly boosted the production of essential commodities (wheat, maize, rice) but has at the same time induced an exponential growth in the use of fertilisers and pesticides poisoning air, water, soil, animals and humans and making agriculture the main cause of biodiversity loss.

In the processing and retailing sectors, heavily processed food, generally rich in calories and poor in nutrients, but with long shelf life, high profits and easy objects of advertising campaigns, are among the causes of the obesity "pandemics" that represent the major cause of deaths by non-communicable diseases.

However, attempts at the introduction of regulations that favour the protection of the environment or the health of citizens are often either undermined along their development by lobbying, or challenged before the WTO as limiting the rights of free trade. Where there is incoherence between trade and the protection of the "public good", the common winner is the former.

A possible challenge is likely to develop also for the implementation of the EC "Farm to Fork Strategy", that sets rather ambitious goals also in the area of agricultural soil improvement, as was made explicit in a recent webinar organised by the European Conservatives and Reformists (ECR) party in the European Parliament ("Food Security in a Post-COVID World: Innovation and Farm to Fork Strategy", 29 July 2020) by the US Secretary of Agriculture Sonny Perdue, who has voiced concerns that the EU Green Deal, of which the Farm to Fork Strategy is an essential pillar, could undermine trade.

Even in cases (such as GATT) that contemplate exceptions to free trade motivated by health protection, environment, etc., this possibility is more theoretical than practical. Even the "precautionary principle" is contested by requiring reference to standards negotiated in fora where private interests have a powerful voice. A convergence of "interests", "ideas" and "institutions" locks in the debate between "private" and public priorities into a stalemate. Of private interests we have discussed before; "ideas" make reference to dominant paradigms, such as the "neo-liberal" primacy of individual economic initiative, competitiveness, sacredness of private profits and the dominance of individual responsibility for behaviours and choices; preference for healthy lifestyles, diets, attitudes towards climate and the environment are depicted as depending on individual rationality. The power of advertisement in shaping personal preferences is wilfully dismissed. Institutions reinforce this lock-in situation by the powerful influences of major economic

21 Friel S., Schram A and Townsend B. 2020. The nexus between international trade, food systems, malnutrition and climate change. Nature Food 1, 51–58. www.nature.com/natfood.

players and organisations over policy makers, often unperceived as such by policy makers themselves.

Overcoming this lock-in, in which issues regarding soil protection is also captured, requires building alternative frameworks by showing the connections between well-being and a broad range of under perceived essential factors. An obvious example is the debate on soil sealing, urban sprawl, expansion of infrastructures in which return on investments, job creation, economic opportunities dominate, rather than the negative effects on water cycles, floods, destruction of habitats; the demonstration is that, despite official statements, the contraction of agricultural land around cities is still growing at a rate that exceeds the rate of population increase, often at the expense of the most productive agricultural land, thus compromising the rural-urban relationships of food systems advocated in public policy declarations (e.g. in the Milan Urban Food Policy Pact: "*Promote and strengthen urban and peri-urban food production and processing based on sustainable approaches and integrate urban and peri-urban agriculture into city resilience plans*").

Soil-related services, individually and globally, need to be recognised as priorities along with other natural resources. In order to achieve this goal an interdisciplinary approach is needed to address the tensions and contradictions between trade and economic interests on the one side and quality of the living environment in a space and time perspective on the other side.

There is a clear role for research here, connecting the dots, showing the interrelated nature and absolute necessity of environmental services; but also a role for a reinforced involvement of society in the debate. The environmental services, rather than the inherent soil characteristics that shape them, are recommended as a main anchor point in a dialogue with citizens. The discussion on trade policies avoids holistic approaches, but rather focuses on the application of specific details of trade rules to curb any undesired deviation from the status quo. An open transdisciplinary and intersectoral approach to issues of global social significance can help shed light on viable forward pathways.

Global environmental outlook[22]

The sixth Global Environmental Outlook (GEO-6) provides a timely overview of the status and perspectives of the main issues regarding the environment at the world scale, including land and sea, forests and agriculture, air, water and soil in an integrated holistic manner, including social factors in the picture. Compared to earlier Global Environmental Outlooks, GEO-6 for the first time distinguishes between land and soil thereby further emphasising on the qualitative, health related aspects of the (3 dimensional) soil body when compared to the mere land.

The links between the different aspects of environmental health and quality are emphasised, as well as the strong influence of human activities on biodiversity, climate, and land use. Economic development is the main driver of all impacts but GDP persists as the principal criterion for measuring development worldwide. The consumption of resources, including soil, is linearly correlated with GDP and personal behaviours, or actions depending on decisions of individuals for their private life, are responsible for 60% of the total environmental impact and traded goods, meant to satisfy household demand, are responsible for 30% of CO_2 emissions.

A decoupling of wellbeing from resource consumption is therefore a number one priority if a sustainable use of natural resources is to be achieved. Inequality of access to resources is a dramatic reality but also probably the main factor acting against the achievement of a sustainable development, with the developed nations (and the wealthy everywhere)

22 UN Environment. 2019. Global Environment Outlook – GEO-6: Healthy Planet, Healthy People. Nairobi. DOI 10.1017/9781108627146.

reluctant to share what they can afford by sheer economic power and the developing nations rightly aspiring to close the welfare gap.

A weakening multilateralism in international relationships is a further obstacle to any coordinated action towards a preservation of the environment as a common good. Inevitably, a resurgence of nationalism ("us first!") represents an obstacle for any progress.

Food systems, that are responsible for a quarter of CO_2 eq. emissions, of 70% of freshwater withdrawals, of biodiversity loss, of land use change, should radically change, especially in consideration of persistent growth of world population, concentrated in the areas most vulnerable to climate change and related phenomena (droughts, floods, desertification, …)

A change in dietary patterns, with reduced consumption of animal source food, is likely inevitable, as well as a reduction of waste; two developments that should and could proceed in sync. Substituting meat with plant-based proteins, at least partially, would free huge areas now dedicated to feed production to be dedicated to human food production.

Of the "habitable" land (71% of global land, after the exclusion of glaciers and barren land), half (51 Mha) are used by agriculture; 77% of it is dedicated to livestock, either for grazing or for the production of feed. But livestock contributes to only 17% of calories and 33% of proteins in human diets and is thus a rather inefficient way to provide humanity with the food it needs.

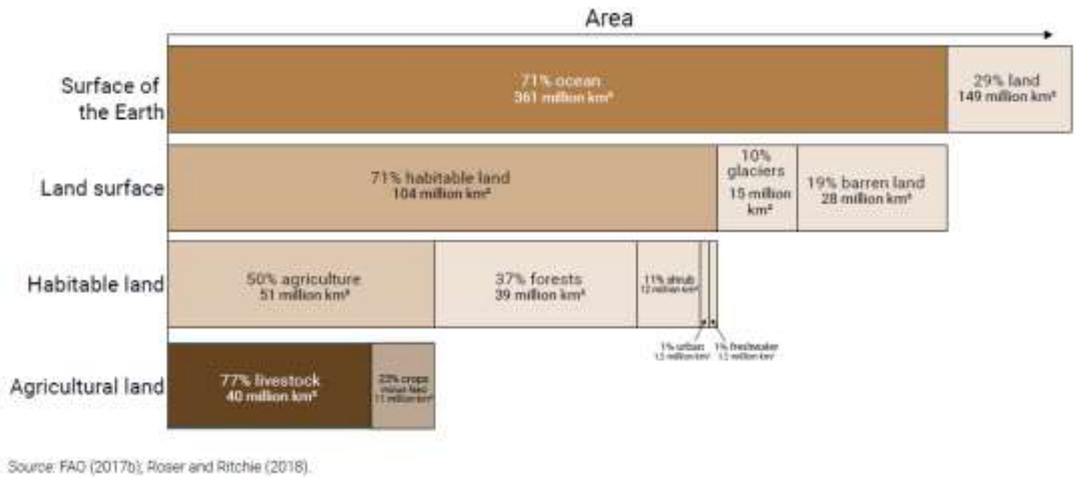

Figure 6 Global surface area allocation for food production.
Sources: FAO (2017b), Roser and Ritchie (2018)

The livestock sector turns the food production systems into the major causes of habitat destruction and the main reason why planetary boundaries for Nitrogen and Phosphorus are exceeded worldwide, often at a considerable distance form where livestock products are consumed. European agriculture is "officially" responsible for 10.3% of the EU's GHG emissions and nearly 70% of those come from the animal sector; 68% of the total agricultural land is used for animal production. However, these figures do not account for emissions and land use changes (their primary cause) occurring outside Europe and due to imports (e.g. soybean and palm oil), attributed by UNCC to the countries of origin. The amount of land corresponding to EU imports is between 30 and 35 Mha, roughly the size of Italy and located in areas where concerns for environmental preservation, the rights of native populations and the rule of law are much, much weaker than in Europe.

Food production is also a major polluter; despite significant progress in the regulation of pesticides and fertilisers, new chemicals are produced and introduced in agriculture before their effects on human, environmental and soil health (especially long term) are properly understood and appreciated.

Environmental accounting suffers from two major flaws that need to be addressed: a) lack of consistent, uniform, official statistics that prevent the comparison of data and justifies disagreements on measures to be adopted; b) inadequate approach to the monitoring and assessment of policy impacts and of the evaluation of consequence of inappropriate use of resources; conventional economic analysis has been often applied, trying to attach a monetary value to costs and benefits of human actions. U.N. SEEA provides a framework for environmental accounting, but consistent stats and monitoring will be vital for success in the application. Conventional economic analysis assumes that any factors can be exchanged (substituted) by a conveniently priced alternative. However, when applied to human subsistence, this kind of reasoning fails miserably, as some rights (to clean air and water, to healthy soil and food, to the maintenance of ecosystems' integrity) are not negotiable and cannot (morally) be appropriated by private interests.

Another strong element of pressure on land and ecosystem integrity is increasing urbanisation; it is estimated that 2/3 of the world population will live in cities by 2050. Well, the "land equivalent" of cities, as measured by its demands, is much larger than the share of land occupied by urban settlements. Therefore, any small percent of expansion of cities (now below 3% of habitable land) will have a disproportionate effect on landscapes and environmental boundaries. The land-degradation-neutrality target of Rio+20 appears out of reach already.

Forests in Europe are a patchwork of local situations. In some areas they are expanding (although mainly as a consequence of the abandonment of agricultural land); elsewhere they are stable; almost nowhere in Europe are they declining in terms of surface. However, the tendency for overexploitation driven by energy production should be considered, as no wide-scale reliable data exist as to the "carrying capacity" of forest ecosystems, that is, the amount (and type) of biomass that can be extracted without compromising soil fertility.

What is apparent is that the initial enthusiasm for forests as producers of bulk feedstock for bioenergy and biomaterials has faded recently; which is good for avoiding nutrient mining from soils. Forest soil fertility indicators, as well as measures to preserve or improve it should become a priority in soil science.

Despite the difficulty of a dialogue between segments of society that do not share a common view on interests and values, a holistic, comprehensive approach towards our common goods is necessary.

1.5. Food systems (Transitions, behaviours, lock-ins)

Food systems, health of people, health of the environment[23]

The authoritative "EAT-Lancet Commission report" represents an attempt at reconciling the complex system of food production and consumption with the "planetary boundaries" that Rockström[24] (and other Authors, since) indicated as environmental limits that could trigger an irreversible environmental decline if trespassed. Several of these boundaries are directly (e.g. Biogeochemcal flows: Nitrogen and Phosphorus use in agriculture) or indirectly (e.g. freshwater use, climate change, biodiversity, land system changes) connected to soil functions and soil health.

The disproportionate effect of food systems on the environment (50% of habitable land dedicated to food production) means that whatever happens in food systems translates in positive or negative consequences for our planet.

The main message of the EAT-Lancet Commission is that changes in diets would bring significant benefits both to human health and to our planet. A "universal diet" was proposed

23 Willett W et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. Published online January 16, 2019 http://dx.doi.org/10.1016/S0140-6736(18)33179-9

24 Rockström J et al. 2009. A safe operating space for humanity. Nature 461, 472–475. doi: 10.1038/461472a; pmid: 19779433;

that is sufficiently flexible to be compatible with what is actually available to consumers across continents and compatible with cultural traditions; this diet fulfils two simultaneous objectives: improving human health and safeguarding the environment. It is interesting to note that the diet is not dissimilar to what National Dietary Recommendations suggest, but significantly different from actually observed diets.

The main difference between the "universal diet" (and NDRs) and actual diets in many parts of the world, is the consumption of meat, red and processed meat in particular, as well as a deficiency of fruits, vegetables, seeds and nuts. This conclusion has provoked understandable reactions from the livestock sector that would be significantly downsized in case of a general adoption of the recommendations.

A shift of diets away from animal source food with a higher intake of plant food (especially plant proteins) would reduce NCDs and at the same time drastically diminish the negative impact of agriculture on climate and the environment

The impact of livestock on land use (77% of agricultural land dedicated to feeding animals) and its contribution to GHG emissions (methane and NO_2 from enteric fermentation and manure) clearly point at meat (and other animal source food) consumption as the most obvious point of attack for the achievement of a sustainable system, without, however, forgetting a broad range of other agronomic options available to achieve this goal.

Significant improvements in the management of Nitrogen and Phosphorus can be achieved, including the implementation of a circularity approach to their cycles, e.g. by recovering N and P from urban sewage.

However, the complexity of the technical, cultural, economic and social interactions in food systems call for a holistic approach combining research, policies, regulations, incentives and bridging the gaps between sectors, not only in science but also, and probably as a priority, between administrative responsibilities: health, education, trade, agriculture, transport, environment, etc. where silos are even harder to break than between scientific disciplines.

The recommendation of the EAT-Lancet Commission is to act on five main strategies:

1. seek international and national commitment to shift towards healthy diets
2. reorient agricultural priorities from producing large quantities of food to producing healthy food
3. sustainably intensify food production, generating high-quality output
4. strong and coordinated governance of land and Oceans
5. at least halve food loss and waste, in line with global SDGs

However, the main obstacle towards the implementation of a radical change in food systems is represented by the influence that vested interest exert on policy makers. The livestock sector in Europe represents more than half of the agricultural GDP and the Food and Beverage Industry is the largest industrial sector both by turnover and jobs, sufficient reasons to intimidate politicians against any drastic change.

Factors locking the agricultural system in a conventional (industrial) model[25]

This IPES-Food report explores the windows of opportunity and the obstacles for a shift in agriculture and food systems from the now dominant "industrial" model to a paradigm

25 IPES-Food. 2016. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems. http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

characterised by diversity, nutritional quality, shared benefits, based on agroecological concepts.

It identifies factors that lock the transition from the current agricultural model, based on large scale monocultures and heavy application of external inputs (energy, chemicals, water) that has proved to be the main cause of environmental degradation: loss of biodiversity, loss of soil organic carbon, soil erosion and compaction, depletion and pollution of water resources, as well as hazards to the safety of farmers and, occasionally, of consumers, while, at the same time failing to provide adequate and healthy nutrition to large parts of the world population.

Despite the explicit focus on Agroecology as the target, the report has a general validity as the lock-in factors are preventing any significant change of paradigm in food systems. The current dominant model (at least in the developed world, but increasingly common, often imposed, in developing countries) is the product of the Green Revolution that had immense merit in shifting millions of people out of hunger, but came at the cost of a large and persisting environmental burden.

The lock-in factors act in conjunction, as the current system has an internal coherence, with individual components adapting and reinforcing one another.

1. **Path Dependency**. The drivers of the development of the current industrial model are essentially a response to increasing labour costs and decreasing energy costs; this has pushed to investments in heavy machinery that needs economies of scale to justify itself, leading to larger farms, monocultures, large scale use of fertilisers, pesticides and irrigation and the development of varieties that best respond to inputs. Mass production of uniform crops (especially cereals, but also soybean and palm oil) has pushed commodity traders and retailers towards reliance on continuity of supply of uniform biomasses.

2. **Export orientation**. Farm production is aimed at the market and depends on the market for inputs. The closure of production cycles within the farm, even when technically feasible, has given way to trade as the new normal. The integration of livestock in cropping systems, once the norm, has given way to specialised meat and milk productions without land, relying on purchased feed and on disposing of effluents outside the farm. The orientation towards export has also been adopted by developing countries as a way to secure foreign currency, often pushed by World Bank directives, but at the cost of large-scale eviction of small farmers.

3. **The expectation of cheap food**. Mass production of a few commodities and their worldwide trade, favoured the development of industrial processing and the production of highly processed food at low cost. Processed food incorporates more value added to cheap feedstock, longer shelf life, appeal for customers. This may have contributed to reducing hunger, but not nutrition, as heavily processed food is usually rich in calories, fat and salt but poor in essential vitamins and micronutrients, leading to dietary deficiencies and obesity. However, the competition of processed food with more nutritious, but more perishable fruits and vegetables inevitably favours the former.

4. **Compartmentalised thinking**. The different components of the industrial agriculture system reinforce one-another: large scale production of uniform materials determine a focus on the least possible number of highly responsive cultivars by major breeders. Patents, breeder's rights and seed laws discourage investment by breeders in diversity and in minor crops. Genetic research, in turn, is increasingly carried out or funded by big private players on their priorities, often imposed also on the agenda of public institutions. Farmers are increasingly dependent on input sellers for obviously biased technical information. Public policies are generally designed to preserve the status quo and the positions of incumbents.

5. **Short-term thinking**. Perspectives of politicians rarely exceed the next electoral term; industries focus their attention on quarterly earnings; farmers are discouraged from transitioning to unconventional production systems by the upfront costs. All this contributes to maintaining the current system, along the whole chain, in place.
6. **"Feed the world" narrative**. The widespread belief that specialised large scale production of commodities and international trade is needed to produce enough food (calories?) for all is hardly challenged and false at the same time. Availability is confused with accessibility/affordability: poverty is the main factor responsible for undernourishment and poverty, in many cases in the developing world it is caused by cheap exports by the main producers that undermine local production. The "feed the world" narrative is a convenient shield for the interest in preserving the status quo and the current production models; even the "sustainable intensification" myth (produce more on the same land by increasing the efficiency in the use of inputs) that would "spare" natural ecosystems from exploitation, has proved false. The "Jevon's paradox" translates increased efficiency into more convenient, and then more invasive, exploitation of lands.
7. **Measures of success**. Conventional (industrial) agriculture measures success in a rather narrow set of criteria, such as total yield of a specific crop, productivity per worker or TFP (total factor productivity). This approach fails to give due consideration to the value of ecosystem services, the improvement to environmental conditions, the creation (or destruction), nutritional value of products, resilience towards physical or economic disturbances, social cohesion of rural communities, etc. This dichotomy, but specifically the failure of current economic analysis to fully grasp the complexity of the picture through a systems approach keeps the dialogue between advocates of more sustainable food systems and defenders of the status quo a dialogue of the deaf.
8. **Concentration of power**. Between two billion farmers and almost 8 billion consumers the food chain displays an impressive series of bottlenecks. Production of fertilisers, agrochemicals, machinery, animal and plant genetic materials, as well as international commodity trade, food processing and retailing are dominated by a surprisingly small number of players operating all over the world, determining the range of choices available to producers and the behaviours of customers. These concentrations of economic power have the capacity to affect the decisions of policy makers by lobbying, by threatening to move businesses, by dictating the agenda of public research. IPES-Food has dedicated a specific report[26] on the threats that such concentrations of power imply for the sustainability of food systems.

The benefits of diversified agricultural landscapes, farms and fields on soil conditions are evident. Conventional (industrial) agriculture is the major cause of leakage of nutrients (nitrogen and phosphorus) and sediments into surface water, of water and wind erosion, of a continuous loss (estimated at 0.5% per year) of organic matter leading to a release of carbon into the atmosphere and loss of nutrient retention capacity.

In turn, the loss of fertility induces a greater and greater application of synthetic fertilisers, further exacerbating the pollution of soils and waters, whereas livestock manure could contribute to soil fertility in a sustainable manner where animal farming is integrated into crop systems.

Improved soil capacity and **soil cover** that reduces evaporation translates into more water available to crops and reduced recourse to irrigation with increasingly scarce blue water.

26 IPES-Food. 2017. Too big to feed: Exploring the impacts of mega-mergers, concentration, concentration of power in the agri-food sector. www.ipes-food.org

A holistic approach to soil health means framing the issue within a broader context and the recognition that a non silver-bullet technological fix is available but solutions need to include social and cultural aspects.

The only clear message from mounting evidence is that the current industrial model is not sustainable under any general point of view, other than the short-term profits of those subjects that still reap the economic benefits while putting the burden of lost environmental services on the shoulders of the majority.

1.6. Forests, forest soils and ecosystem services

According to FRA-2015 (FAO, 2016), forests represent the second largest type of use of land: 3.999 M ha or 30.6% of land (excluding Antarctica and Greenland). Forests differ greatly around the world and have a broad range of functions at the global and local scale, depending on climate, demography, social and economic contexts (HLPE, 2017). The official FAO definition includes tree plantations (expanding in all continents) but excludes agroforestry systems.

Deforestation rates are still positive but declining and this trend is expected to continue. Over the last three decades, the forests expand in the temperate regions of the world and decrease in the tropical regions, with boreal forests (mainly N.Europe and Canada) and subtropical forests almost stable over the same period. Whereas the area of primary forests is expected to follow a progressive reduction, the total forest area is expected to rise from 2020 onwards; more rapidly so in OECD countries, followed by BRIICS[27] and, at a later date (2030) by the rest of the world (OECD, 2012).

Excluding Russia, (with its 815 Million hectares), European forests cover an area of 215 Mha, or 33% of its territory (Forest Europe, 2015), with Sweden (28.1 Mha), Finland (22.2), Spain (18.4) and France (17,0) in the lead. Finland (first) and Sweden (second) also display the highest proportion of forest area with respect to total country surface. European forests are expanding in almost all countries and stable in Sweden and Finland.

Forests, probably even more than agriculture, display a broad range of interconnected functions and services, typically simultaneously in the same area, that depend on the local climatic, ecological, demographic/ethnographic, social, and economic situation.

Forests and ecosystem services

Production of wood - The utilisation of forests for production of industrial roundwood is favoured where access with operational machines is easier. The contribution of forestry and logging to GDP (not considering downstream industrial transformation) however, is low; in general, the higher the national income, the lower its share (FAO, 2016). Employment in forestry and logging parallels GDP: lowest in high income countries (largely due to mechanisation), higher in lower income countries: the perspectives are of further decline in developed countries. The main trends observed in the international market of forest products is of an increase of sawn wood and panels *vs* roundwood, a decrease of the printing paper sector offset by an increase of cardboard for packaging. The market of wood chips for the production of energy is still volatile, as no clear position is so far broadly accepted on the role of forests as sources of renewable feedstock for biomass power plants.

The amount of wood harvested expressed as a ratio to annual increment is on average around 60% in Europe (UNECE/FAO, 2015). However not in itself the ultimate index of a good forest management and with the caution that is recommended when average data are used, it shows that, in general, European forests are not subject to an impoverishment of its living biomass resources, but, rather, that they are progressively accumulating wood.

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27 Brazil, Russia, India, Indonesia, China, South Africa

However, in recent years, the difference between fellings and increment is decreasing, due to an increasing interest for renewable raw materials for industry and energy.

Provision of energy It is estimated that wood represents around 6% of total energy supply (or 40% of all renewable energy), with a share of up to 27% in Africa (FAO, 2016) and down to 2.5% in Canada. Wood for heating and, to a lesser extent, for cooking, is also important in high income countries: most of coppice forests of central and southern Europe produce fuelwood for private heating.

Provision of food The degree of dependence of populations living in or near to forests on food collected in the forests depends greatly on the circumstances. In high income countries, such as in Europe, non-wood forest products (NWFP) are locally important for economic, cultural and recreational purposes. The collection of mushrooms and berries is often regulated in Europe, with rules, norms, habits, customs varying across states and often locally; together with hunting (licensing and hunting rights) and bee products, it represents the main sources of non-wood revenues in European forests.

Environmental functions Water regulation, erosion control, soil protection, nutrient circulation, are all actions performed by forests in various degrees. The importance of forests for the preservation of fundamental ecosystem functionality has been remarked by Steffen *et al.* (2015) who proposed "Land-system Change" as one of the planetary boundaries, with an indicator being the area of forested land as % of potential forest in different biomes.

Climate change mitigation (and consequences of climate change on forests) The subject of carbon sequestration is open to debate. A typically mature forest where a balance between carbon captured by vegetation growth and its release by decaying biomass is most likely neutral, unless more biomass can be permanently added to the soil in stable form than is released. Harvesting of logs (especially from plantations) has the potential to return the carbon to the atmosphere, albeit with a delay depending on use (construction and furniture are usually ways to achieve long term locking of carbon). In construction, wood can often replace concrete and steel, both energy intensive materials. However the substitution effect is difficult to quantify in the real world (UNECE/FAO, 2015). More delicate is the issue of first-generation energy production by burning woody biomass; a zero-balance between carbon captured by growing trees and carbon released can never be reached due to energy employed or lost in the conversion; however, a "substitution" concept can be invoked, meaning that the alternative "fossil" energy would be significantly more negative in terms of net CO_2 emissions.

The effect of climate change on forest ecosystems has been a matter of speculation rather than of conclusive evidence. There is a possible benefit to biomass production from increased CO_2 concentration in the atmosphere, as photosynthesis uses CO_2 as input for the production of carbohydrates. Higher average temperatures might extend the growing season by an earlier spring initiation and later autumn cessation of annual growth. However, evidence is inconclusive and such positive effects would certainly depend on latitude, with Northern forests the most likely beneficiaries. On the other hand, shifting climatic zones towards higher latitudes and altitudes threaten the ability of forest ecosystems to follow the trend, as the colonisation process of long living organisms might be slower than the climatic shift, depending also on the specific mechanisms of seed dispersion and the degree of genetic diversity, essential for evolution. On the southern fringes of forest species ranges, the conditions might become inhospitable before any genetic adaptation can become effective.

The main threats from climate change, however, are probably not progressive changes of average conditions but a higher frequency of extreme climatic events, from prolonged droughts to floods and windstorms. On the biotic side, attacks from new pests from lower latitudes that find viable conditions to invade more northern areas have already be observed. Native pests may have more generations per year, reduced winter mortality, and thus provoke damages rarely seen in the past (EEA, 2016).

Preservation of biodiversity Forests are by far the land environments richest in species of all *phyla* when compared to agricultural ecosystems of the same climatic regions. The conservation of biodiversity is essential for maintaining stability of the environment, preserving the ability of species to evolve. Most European Forests (over 90%) are ecosystems modified by man and subject to active management, but still displaying a high level of diversity and thus possessing the ability to function as viable diverse ecosystems. Two thirds (68%) regenerate naturally; the rest are generally replanted after wood harvesting operations (especially in Nordic countries).

Culture, Recreation, Amenity Forests have a cultural, often religious, value in many traditional cultures and a fundamental role also in more secular cultures as key elements of landscapes, areas of choice for recreational activities, sport and tourism. The recreational function of forests is particularly important in Europe where around 90% of their area is accessible to the public (Forest Europe, 2015). It has been estimated that around 60% of Europeans live in or close to forests (EEA, 2016).

There is a widespread debate about the possible "payment for ecosystem services" (PES). However reasonable the idea may appear, there are a number of difficulties in its application. For many ecosystem services establishing a value or a price is not straightforward as there is not a market; some services are inherent in the very existence of a forest, so that a compensation could be conceivable only in case of onerous but discretionary management decisions. There is a need for research that enable on the one hand an evaluation of the economic value of services and on the other hand the costs (better, cost opportunities) of different management decisions, with the added difficulty that both are likely to differ considerably in different environments as well as the categories that would benefit from the services and should therefore be the subjects who pay for the services (EEA, 2016).

Complexity requires site-specific management solutions

A variety of functions means a complex interaction of rights and expectations by different groups of stakeholders. Ownership of forests in the world varies considerably, from almost entirely public to almost entirely private. The same occurs in Europe, with most of the countries of the former Eastern bloc having the largest proportion of public forest.

However, on the one hand both public and private ownerships have a range of types of owners (state, region, community, publicly owned institutions; individuals, families, cooperatives, for-profit or not-for-profit organisations) with different objectives and priorities; on the other hand, only rarely has the owner exclusive rights on its property; most frequently a range of users have legal or customary rights of access, collection of mushrooms and berries, collection of dead wood and litter, hunting, foraging. Rules and rights vary considerably from country to country.

In many countries, private rights on the use of forests are limited by overriding public interest dealing with landscape preservation, slope stabilisation, protection of water resources, nature conservation etc.

Sustainable Forest Management

Forest Europe[28] (formerly the Ministerial Conference on the Protection of Forests in Europe) defined SFM as the "*stewardship and use of forest lands in a way, and at a rate that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels and that does not cause damage to other ecosystems*". This

28 **FOREST EUROPE is the "**brand name" of the Ministerial Conference on the Protection of Forests in Europe, a pan-European voluntary high-level political process for dialogue and cooperation on forest policies in Europe. Its members are 46 European countries and the European Union.

definition, obviously generic, echoes the principle of sustainable development as proposed in the "Bruntland report" (Our Common Future) of 1992.

There is not universal agreement on the idea that SFM incorporates the concept of Ecosystem Based Management (EBM) of Forests, that emphasises the focus on the preservation of biodiversity, the functionality of ecosystems and the provision of ecosystem services (or vice-versa, that EBM incorporates SFM)(EEA, 2016).

At the local level voluntary, private certification schemes of sustainable forest management (SFM) are spreading. The most common are FSC (Forest Stewardship Council, supported by environmental NGOs) and PEFC (Programme for the Endorsement of Forest Certification, with a strong base in forest owners). Both aim at the dialogue between the different stakeholders in the definition of forest management plans. FSC has a top-down approach, with basic principles that have to be applied in all circumstances, however adapted to local situations; PEFC has a more bottom-up approach aiming at an agreement on objectives locally shared by the stakeholders.

The European forest area under sustainable management, however, is certainly broader than that certified by FSC or PEFC (sometimes by both, simultaneously). Failure to certify a forest property may depend on lack of perceivable benefits for the owners or on purely economic inability to cover the costs of the certification process, especially by small private owners (UNECE/FAO, 2015).

Forest Management Plans, i.e. periodically revised plans documenting the intended use of forest land, are an essential component of SFM and are being gradually applied around the world. Europe, where the tradition of rational forest management was first developed, is leading, with 94% of forests managed according to a formal plan (FAO, 2016).

Forest soils

Forest soils are extremely variable according to latitude, type of bedrock, altitude, slope, rain regimes etc. In many circumstances, especially in dry/warm climates, any perturbation from fires, excessive logging, etc. leads to an irreversible decline. The main objective of any management decision and any forest operation should be to avoid soil disturbances or make their effect as transitory as possible.

In the foreseeable future, a significant threat to forest ecosystems and forest soils in particular, is represented by the increasing interest of the wood industry and the renewable energy industry in trees as a renewable raw material in the context of the Bioeconomy whose principal aim is to replace oil and other fossil carbon feedstock with biomass.

A compromise (or a priority order) between competing objectives must be achieved, albeit at a regional level, between:

d) maximisation of the role of forests as carbon sinks (both above and below ground);
e) maximisation of biomass production;
f) maximisation of biodiversity preservation.

The main risk of having the maximisation of biomass as a leading priority, especially for the production of energy, is that of a progressive impoverishment of soil fertility leading to a decay of long term forest health. Increased removals of harvest residues (barks, stumps, tree tops and branches) leads inevitably to a loss of nutrients and fertility (in addition to reduced water storage capacity, susceptibility to erosion, loss of diversity)

A public debate should inform decisions and a widespread knowledge should inform it, as it often appears more ideological than rational.

2. Mapping Soil Health Concepts

2.1. Introduction to mapping indicators to objectives, and farm practices to indicators

This mapping exercise seeks to use the current literature to show how indicators map to the six primary mission board objectives (Table 3) and how farm practices, or interventions, map to indicators. We focus on mapping soil health indicators to objectives identified by the mission board (MB) in Table 1 as the starting point. The value of this is to bring out the linkages in an interdisciplinary sense, based on the current state of knowledge. In doing so we also identify some gaps in current knowledge and practice that will be important to take the mission forward. They are considered at the end of the section.

Specific Targets and Indicators			
Objectives	**Land Management Targets**	**Soil Health Targets**	**Six Soil Health Indicators**
Land degradation and desertification	*50% degraded land restored*	*Strong reduction in degradation and desertification*	*All 6 soil health indicators*
Soil organic carbon	*Conservation of high carbon soils and a reverse of carbon loss in croplands.*	*A switch from a 0.5 % loss per year to a 0.1-0.4% increase in SOC concen-tration in cropland soils* *30-50% reduced area of peatland losing carbon*	*Soil organic carbon stock* *Vegetation cover*
Soil sealing and net land take	*Urban recycling of land from 13 to 50%* *No net land take by 2050*	*Switch from 2.4% to no net soil sealing*	*Soil structure including soil bulk density and absence of soil sealing and erosion* *Vegetation cover*
Soil pollution	*25% of land under organic farming* *Doubling of rate of remediated sites prioritising brown field sites*	*5-25% additional land (i.e. over and above the 25% in full organic) with reduced risk from a range of pollutants*	*Presence of soil pollutants, excess nutrients and salts*
Erosion	*50% degraded land restored*	*Prevention on 30-50% of land with unsustainable erosion risk*	*Soil structure including soil bulk density and absence of soil sealing and erosion.* *Vegetation cover*
Soil structure	*50% degraded land restored*	*Reduction by 30-50% of soil with compaction*	*Soil bulk density and other measures of soil structure*
While not being a soil indicator in the strict sense, mission activities will be assessed against their impact on the health of soils outside Europe			
Global footprint	*Strengthened international cooperation; trade regulations, including carbon tax*	*20-40% reduction of current global footprint*	*Food, feed and fibre imports leading to land degradation and deforestation*

Table 3 Objectives of the mission board and the targets and indicators used to assess progress and achievement. (From MB 2020)

The ultimate objective of this exercise is to indicate (to map) which practices can contribute to which objective(s). We have taken a reasonably broad approach, not only mapping what would be considered direct soil health indicators, but also those that affect the system indirectly. We therefore consider three sets of indicators in the mapping:

1) Soil health indicators,
2) Other environmental indicators, and
3) Economic performance indicators

The broader mapping thus includes farm measures such as hedgerow presence and maintenance that could impact indirectly on soil health, and reflects the interdisciplinary approach and the system thinking advocated by the mission board and the recommended building blocks. The set of indicators used in this exercise are summarized in Table 4.

Group	Indicator abbreviation	Indicator explanation
Soil Health	Soil_contaminants	Presence of soil contaminants, nutrients and excess salts and sodicity.
	Vegetation_cover	Vegetation cover (general and on erosion endangered land).
	Organic_matter_content	Change of organic matter content.
	Soil structure	Soil structure (compaction) and surface water infiltration
	Soil_biodiversity	Soil biodiversity. Presence of functional diversity of appropriate bacteria and fungi and of soil animal communities.
	Soil_nutrients	Soil nutrients (N,P, K, S, Ca], and pH
	Soil_sealing	Soil sealing (annual loss of agricultural, forest and wild nature land)
	Degraded_soils	The share of deeply degraded soils on total area
Other environmental effects	Water_quality	Level of pollutants in water, water purity
	Water_retention	Water retention / conservation
	Biodiversity_general	Biodiversity (other than soil biodiversity) / number of species
	GHG_emissions	GHG emissions (from soils)
Economic performance	Yield	Effects on crop yields in contrast to conventional practices
	Costs	Effects on farm costs

Table 4 Considered indicators. Source: JRC (2010), Maskell et al (2019)

In contrast to the MB report we separated the soil sealing indicator from the soil structure indicator (subgroup) as the underlying degradation is often different in nature. Since one of the principal objectives of soil health protection is to reduce the share of degraded soils (particularly eroded) we introduced a 'soil degradation' indicator (or a set of such indicators) to capture the share of deeply degraded soils on the total [agricultural and forest] land (or/and a dynamic form of it i.e. a change).
Farm management practices, beneficial to soil, are also split into two categories:

1) **Basic soil management practices,** which are primarily aimed at improving soil health and are commonly adopted in farm practice appearing in Good Agricultural and Environmental Conditions (GAECs[29]), and
2) **Other relevant management practices,** which are either specific for special conditions or primarily addressing other environmental problems/benefits

These are listed in (Table 5).

[29] Good Agricultural and Environmental Conditions - integrated in the Cross Compliance of the Common Agricultural Policy measures.

Group	Abbreviation of practices	Description of practices
Basic soil practices (common, GAEC adopted)	Reduced_tillage	No or reduced tillage
	Cover_crops	Cover crops
	Crop_rotation	Crop rotation
	Intercropping	Intercropping
	Grasslands	Grasslands, esp. permanent, and their maintenance
	Stubble_crop_residuals	Maintenance and incorporation of stubble and crop residues
	Restrict_row_crops	Restrictions on growing row crops
	Agroforestry	Agroforestry
Other relevant practices	Conservation_buffers	(Conservation) Buffers
	Terracing	Terracing
	Sward_diversity	Sward diversity (≈4 species)
	Strip_cropping	Strip cropping
	Ridge_tillage	Ridge tillage
	Contour_farming	Contour farming
	Subsoiling	Subsoiling
	Delayed_manure_inc	Delayed manure incorporation
	Exog_org_matter	(Appropriate) Use of exogenous organic matter
	Less_anorg_fer	Limited or no fertiliser use
	Less_pestic	Reduced (or no) plant protection/ pesticide use
	Rivers_intens_restr	Restrictions on intensive crop production in riverside areas
	Hedgerow_manag	Hedgerow management
	Appropriate_machinery	Appropriate use of appropriate machinery
	Legumes_on_recult_ag_land	Legumes on re-cultivated agricultural land

Table 5 Selected farming management practices beneficial to soils.
Source: JRC (2010), Maskell et al (2019)

In the final set of mapping we consider three farming systems and attempt to map these to both indicators and objectives. These farming systems are:

i) Organic framing (certified or in the transition to it)
ii) Integrated crop management system (Agra CEAS, 2002)
iii) Conservation agriculture (CA): reduced tillage, retention of stubble and crop residues, cover crop and crop rotation (Marques et a., 2015)

2.2. Approach

The study is not exhaustive and two publications were used extensively as the basis for the analysis. The JRC (2010) report, '*Sustainable Agriculture and Soil Conservation (SoCo) - final report*' specifically reviews interventions used for soil protection in conservation agriculture and organic farming. While the Maskell et al., (2019) report, '*Review of current methods and approaches for simple on farm environmental monitoring of FAB solutions*' focuses on soil and agroecological interventions to support functional agrobiodiversity (FAB). Both reports are based on, and contain, extensive surveys of the literature. Thus in using them we have benefitted from the synthesis of current knowledge and practice they provide, based on the findings of many other research works (which we do not list he but can be found in the two publications mentioned above to learn about the sources of knowledge presented in the tables and charts – maps). We recognise that this will not cover the full spectrum of technologies and practices used, especially when it comes to pollution and land reclamation and restoration.

In the first step we link soil health indicators with objectives, noting that often one indicator serves more than one objective. In the next step we show how management practices are linked to indicators. We provide some expert judgement on the direction of change (positive/ improving, negative/worsening or variable effect by combining). We also provide some judgement on the intensity of the impact, e.g. positive +, strongly positive ++). The summary results of mapping are presented in a tabular format and graphics. The use of symbols and colours in mapping tables and charts is summarised in Table 6

Symbol	Description	Colour in the charts	Evaluation Score
(empty) or 0	no effect		0
-	Negative effect	Solid red	-1
±	Variable effects	Dashed yellow	1
+	Positive effect	Solid green (thin)	5
++	strong positive effect	Solid green (thick)	10

Table 6 Use of symbols and colours in mapping tables and charts.

The size of the node in the graphic maps refers to the sum of the absolute values of the evaluation scores (Table 6), thus it reflects the number of connections associated with the concept (item) as well as judgements on the intensity of the effect. The latter is represented by the thickness of connecting lines too.

2.3. Mapping soil health indicators to mission objectives

Each MB objective has at least one relevant indicator except the seventh objective "Reducing global footprint of the EU's food and timber imports", clearly because soil health indicators must be measured outside Europe - European values are irrelevant (Table 7). For five of the six European soil health objectives there is one strong, highly relevant outcome indicator, while for the soil erosion prevention objective the most relevant indicator is the (annual) loss of soil, which is however difficult to measure. It is often estimated in the EU (Panagos et al., 2015), through the share and quality of vegetation cover on most erosion endangered land, which provides a reasonable (action related) indicator.

	MB Objectives						
Soil health indicators	Reduced_soil_degradation	Increased_SOC	No_net soil_sealing	Reduced_soil_pollution	Prevented_erosion	Improved_soil_structure	Reduced_food_footprint
Soil_contaminants				++			
Vegetation_cover	+				+		
Organic_matter_content.	++				+		
Soil structure						++	
Soil_biodiversity		+				+	
Soil_nutrients		±					
Soil_sealing			++				
Degraded_soils	++				+		

Table 7 Table 2 Mapping MB soil health indicators to MB soil health objectives.
Source: JRC (2010), Maskell et al (2019)

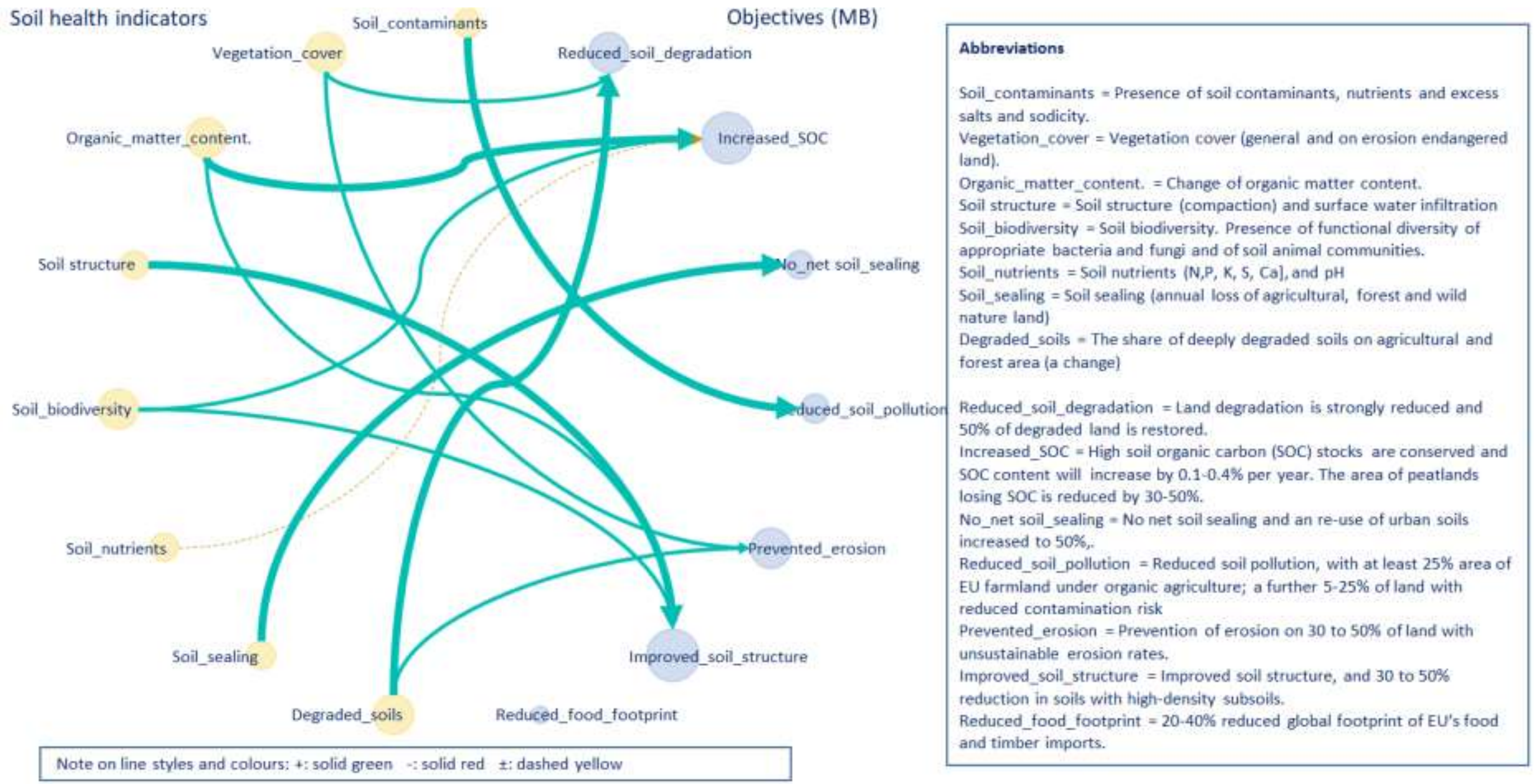


Figure 7 Mapping soil health indicators to Mission Board objectives. Source: Own elaboration based on Table 7

Each MB objective has at least one relevant indicator except the seventh objective "Reducing global footprint of the EU's food and timber imports", clearly because soil health indicators must be measured outside Europe - European values are irrelevant (Table *7*). For five of the six European soil health objectives there is one strong, highly relevant outcome indicator, while for the soil erosion prevention objective the most relevant indicator is the (annual) loss of soil, which is however difficult to measure. It is often estimated in the EU (Panagos et al., 2015), through the share and quality of vegetation cover on most erosion endangered land, which provides a reasonable (action related) indicator.

Note on line styles and colors: +: solid green -: solid red ±: dashed yellow

2.4. Mapping other environmental indicators to the mission objectives

We selected four indicators relating to the other environmental objectives (water protection, biodiversity protection and climate change mitigation). These provide a complementary view as to the benefit of soil health practices. These indicators are highly relevant for the other objectives, which also illustrates how these other environmental indicators link to the MB soil health objectives.

	Objectives (MB)						
Other environmental indicators	Reduced_soil_degradation	Increased_SOC	No_net soil_sealing	Reduced_soil_pollution	Prevented_erosion	Improved_soil_structure	Reduced_food_footprint
Water_quality				+			
Water_retention	+		±		+	+	
Biodiversity_general		+					
GHG_emissions		+					

Table 8 Mapping other environmental indicators to MB soil health objectives.
Source: JRC (2010), Maskell et al (2019)

The second and third indicators in Table 8 are associated with landscape: the capacity of landscapes to retain rainfall water and the number of species in the landscape (delimited area).

Clearly, it is land and its soil parameters which determine, to a large extent, the values of the presented four groups of indicators. Thus these indicators can help assess the achievement of the stated soil health objectives at a range of scales as desired by the MB.

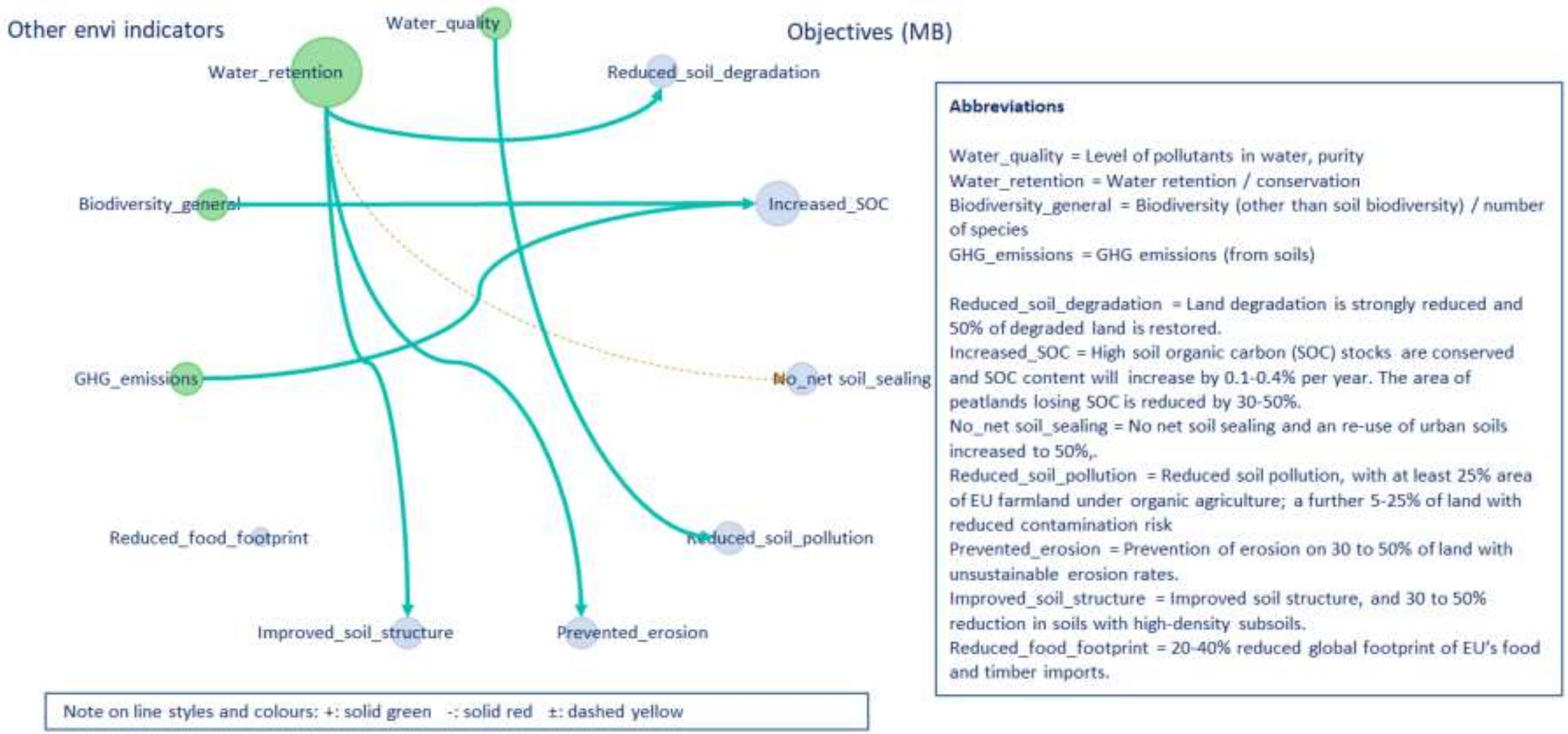


Figure 8 Mapping other environmental indicators to soil health objectives. Source: Own elaboration based on Table 8

2.5. Mapping farm practices to mission soil health indicators

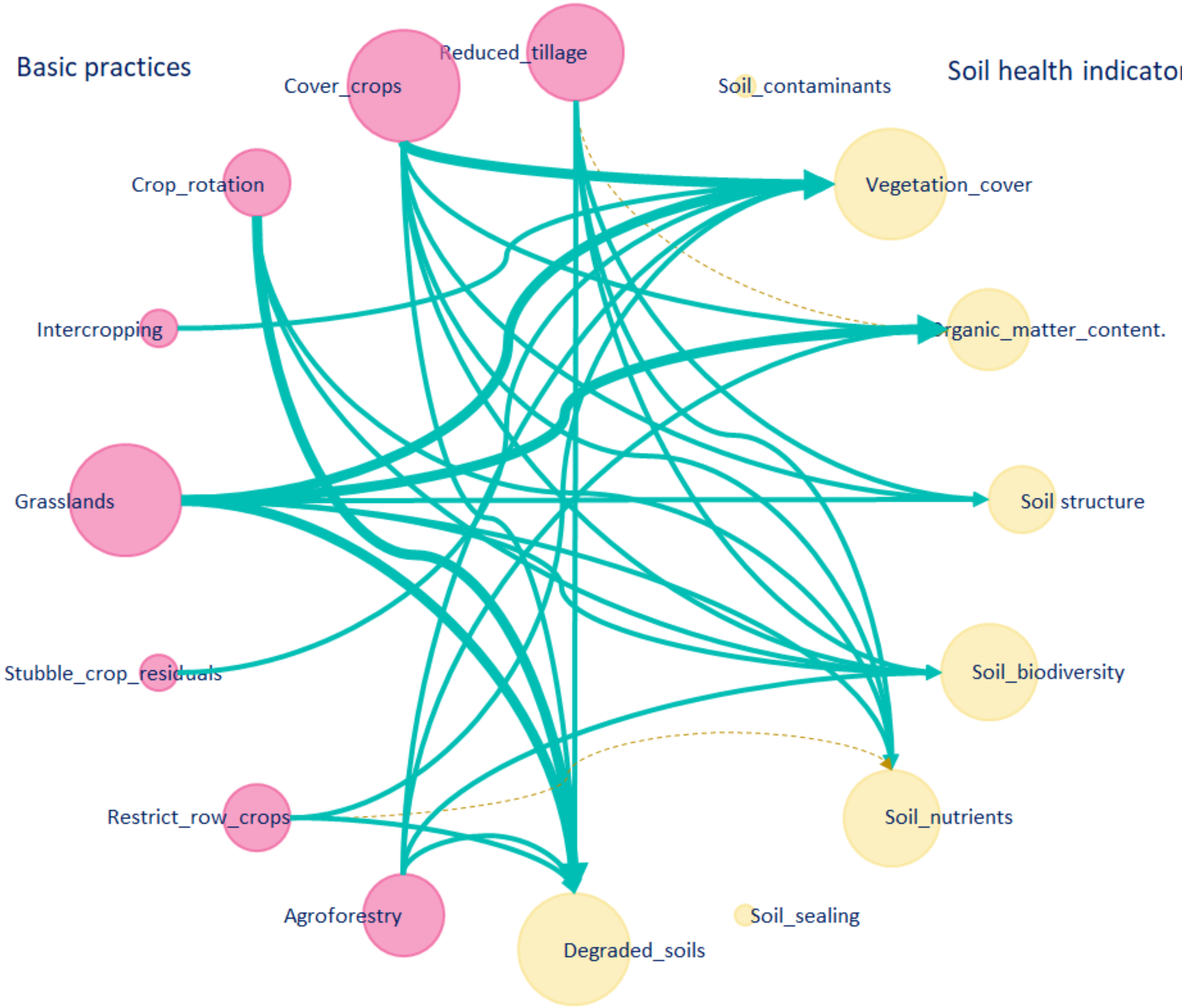
Basic farm practices that contribute to soil health are shown in Table 9. It is worth noting from our review of the literature that grasslands, particularly those well maintained and in extensive use positively affect most of the soil health indicators, often depending on intensity of use. As will be shown later they also have a positive impact on the other environmental indicators (Table 11). However, their opportunity cost is high when grasslands replace arable crops (Table 13)

	Soil health indicators							
Basic practices	Soil_ contaminants	Vegetation_ cover	Organic_ matter_ content.	Soil structure	Soil_ biodiversity	Soil_ nutrients	Soil_ sealing	Degraded_ soils
Reduced_tillage			±	+	+	+		+
Cover_crops		++	+	+	+	+		+
Crop_rotation					+	+		++
Intercropping		+						
Grasslands		++	++	+	+	+		++
Stubble_crop_residuals		+						
Restrict_row_crops		+				±		+
Agroforestry		+	+	+	+			+

Table 9 Mapping basic soil protection practices to soil health indicators.
Source: JRC (2010), Maskell et al (2019)

	Soil health indicators							
Other practices	Soil_ contaminants	Vegetation_ cover	Organic_ matter_ content	Soil structure	Soil_ biodiversity	Soil_ nutrients	Soil_ sealing	Degraded_ soils
Conservation_buffers	+				+			+
Terracing								+
Sward_diversity			+		+			
Strip_cropping		+						+
Ridge_tillage			+		+			+
Contour_farming								
Subsoiling				+				
Delayed_manure_inc								+
Exog_org_matter			+	+		+		+
Less_anorg_fertilisers	++					-		
Less_pesticides	++							
Rivers_intens_restr	++							
Hedgerow_mang.			+					+
Appropriate_machinery				+				
Legumes_on_recult_ag_land						+		+

Table 10 Mapping other soil protection practices to soil health indicators-
Source: JRC (2010), Maskell et al (2019)



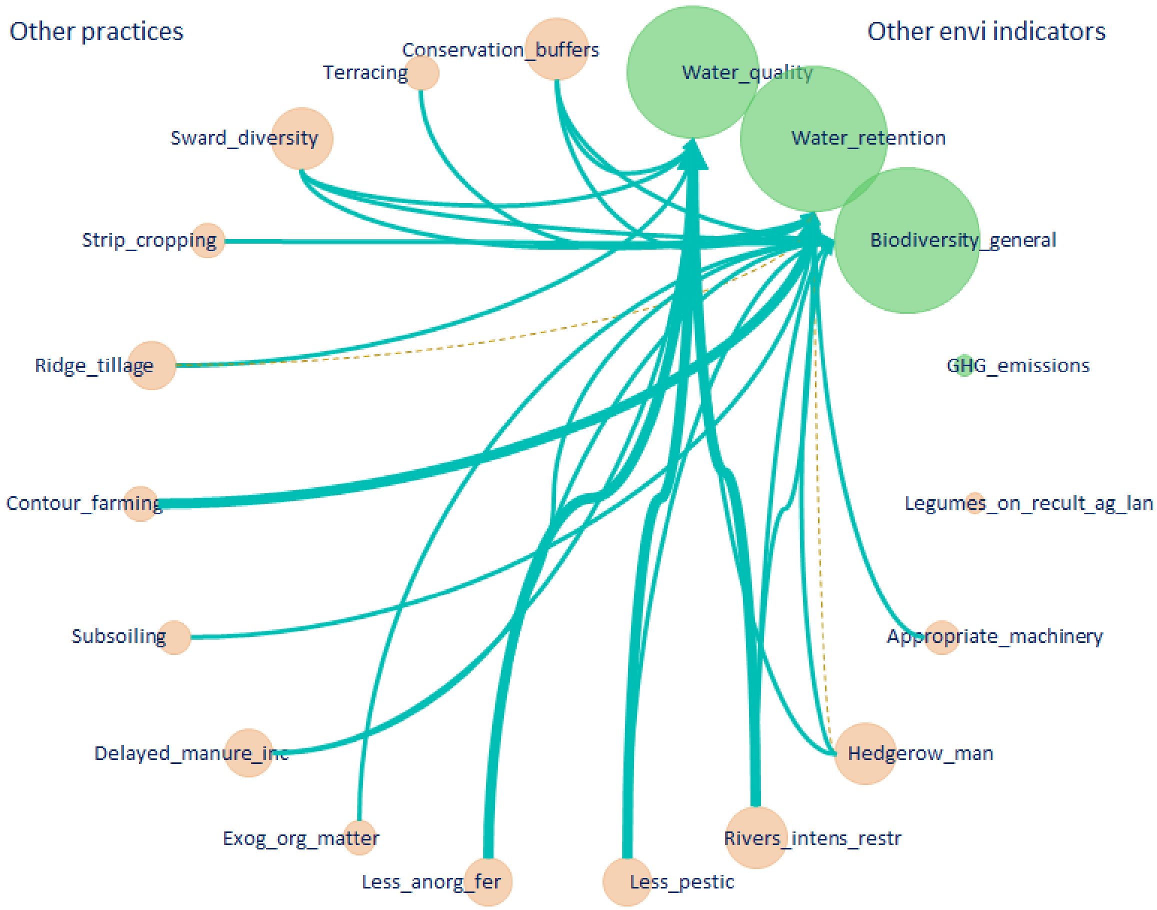
Abbreviations

Reduced_tillage = No or reduced tillage
Cover_crops = Cover crops
Crop_rotation = Crop rotation
Intercropping = Intercropping
Grasslands = Grasslands, esp. permanent, and their maintenance
Stubble_crop_residuals = Maintenance and incorporation of stubble and crop residues
Restrict_row_crops = Restrictions on growing row crops
Agroforestry = Agroforestry

Soil_contaminants = Presence of soil contaminants, nutrients and excess salts and sodicity.
Vegetation_cover = Vegetation cover (general and on erosion endangered land).
Organic_matter_content. = Change of organic matter content.
Soil structure = Soil structure (compaction) and surface water infiltration
Soil_biodiversity = Soil biodiversity. Presence of functional diversity of appropriate bacteria and fungi and of soil animal communities.
Soil_nutrients = Soil nutrients (N,P, K, S, Ca], and pH
Soil_sealing = Soil sealing (annual loss of agricultural, forest and wild nature land)
Degraded_soils = The share of deeply degraded soils on agricultural and forest area (a change)

Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Figure 9 Mapping basic practices to soil health indicators. Source: Own elaboration based on Table 9



Abbreviations

Conservation_buffers = (Conservation) Buffers
Terracing = Terracing
Sward_diversity = Sward diversity (≈4 species)
Strip_cropping = Strip cropping
Ridge_tillage = Ridge tillage
Contour_farming = Contour farming
Subsoiling = Subsoiling
Delayed_manure_inc = Delayed manure incorporation
Exog_org_matter = (Appropriate) Use of exogenous organic matter
Less_anorg_fer = Limited or no Fertiliser use
Less_pestic = Reduced (or no) plant protection/ pesticide use
Rivers_intens_restr = Restrictions on intensive crop production in riverside areas
Hedgerow_man = Hedgerow management
Appropriate_machinery = Appropriate use of appropriate machinery
Legumes_on_recult_ag_land = Legumes on recultivated agricultural land

Water_quality = Level of pollutants in water, purity
Water_retention = Water retention / conservation
Biodiversity_general = Biodiversity (other than soil biodiversity) / number of species
GHG_emissions = GHG emissions (from soils)

Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Figure 10 Mapping other practices to soil health indicators. Source: Own elaboration based on Table 10 Table 9

2.6. Mapping other soil protection practices to other environmental indicators

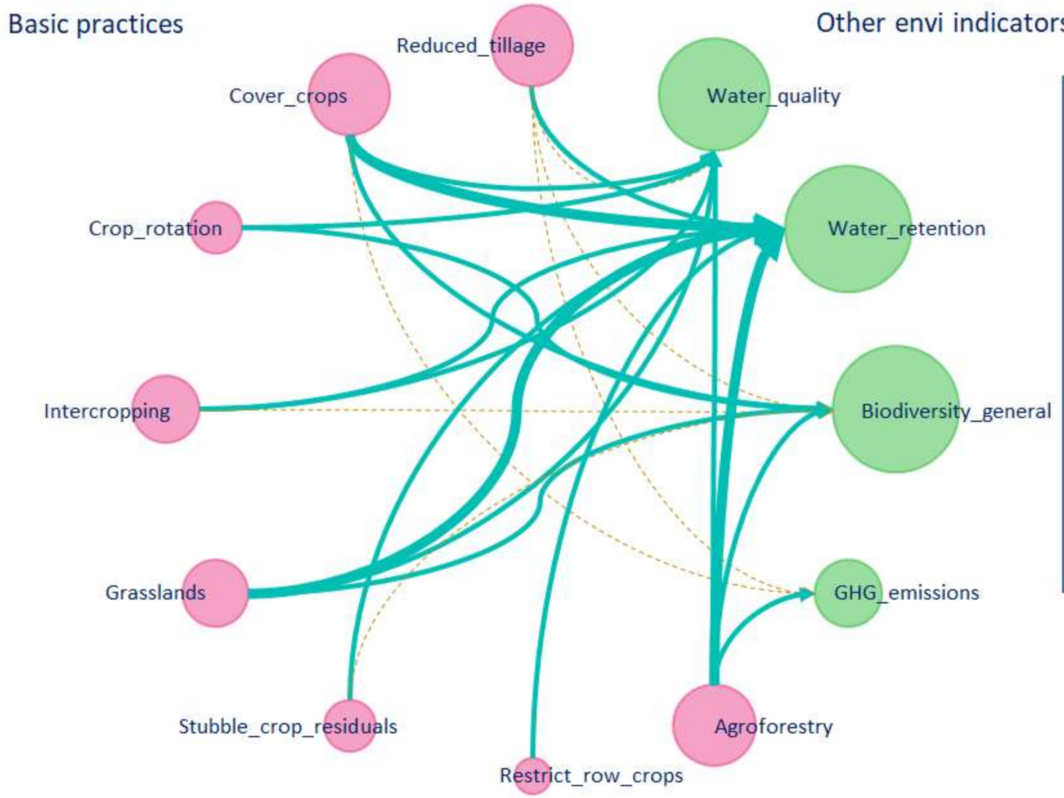
As pointed out earlier soil management practices might affect other environmental objectives (thus indicators) and practices aimed at achieving other environmental objectives, and thus might yield soil health outcomes. Typically, for example, soil and water protection are closely linked.

	Other environmental indicators			
Basic practices	Water_ quality	Water_ retention	Biodiversity_ general	GHG_ emissions
Reduced_tillage	±	+	±	±
Cover_crops	+	++	+	±
Crop_rotation	+		+	
Intercropping	+	+	±	
Grasslands	+	++	+	
Stubble_crop_residuals		+	±	
Restrict_row_crops		+		
Agroforestry	+	++	+	+

Table 11 Mapping basic soil protection practices to other environmental indicators. Source: JRC (2010), Maskell et al (2019)

	Other environmental indicators			
Other practices	Water_ quality	Water_ retention	Biodiversity_ general	GHG_ emissions
Conservation_buffers	+	+	+	
Terracing		+		
Sward_diversity	+	+	+	
Strip_cropping			+	
Ridge_tillage	+	±		
Contour_farming		++		
Subsoiling		+		
Delayed_manure_inc	+		+	
Exog_org_matter			+	
Less_anorg_fer	++		+	
Less_pestic	++		+	
Rivers_intens_restr	++	+	+	
Hedgegrow_man	+	±	+	
Appropriate_machinery		+		
Legumes_on_recult_ag_land				

Table 12 Mapping other soil protection practices to other environmental indicators. Source: JRC (2010), Maskell et al (2019)



Abbreviations

Reduced_tillage = No or reduced tillage
Cover_crops = Cover crops
Crop_rotation = Crop rotation
Intercropping = Intercropping
Grasslands = Grasslands, esp. permanent, and their maintenance
Stubble_crop_residuals = Maintenance and incorporation of stubble and crop residues
Restrict_row_crops = Restrictions on growing row crops
Agroforestry = Agroforestry
Water_quality = Level of pollutants in water, purity
Water_retention = Water retention / conservation
Biodiversity_general = Biodiversity (other than soil biodiversity) / number of species
GHG_emissions = GHG emissions (from soils)

Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Figure 11 Mapping basic practices to other environmental indicators. Source: Own elaboration based on Table 11

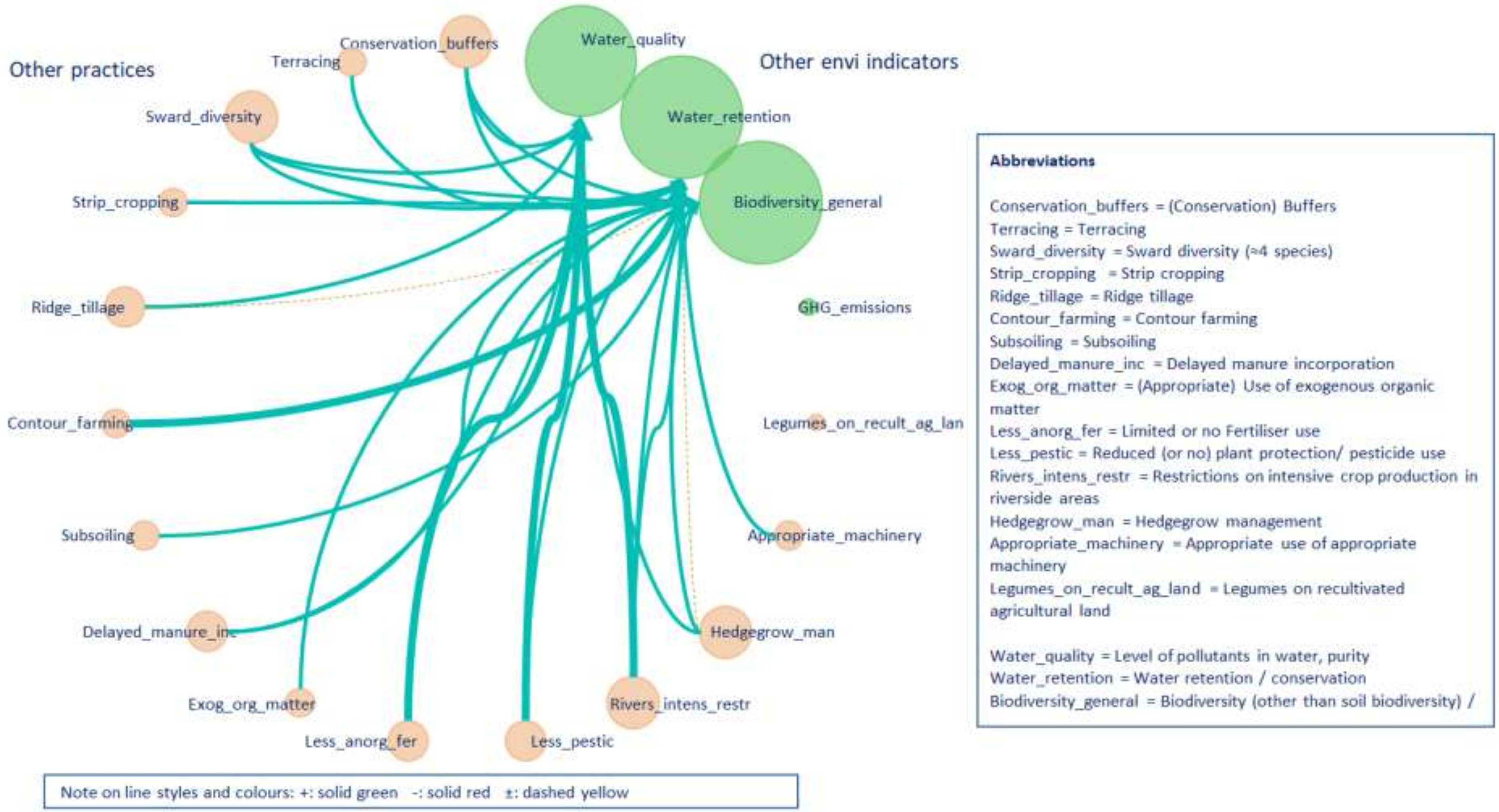


Figure 12 Mapping other management practices to other environmental indicators. Source: Own elaboration based on Table 12

2.7. Mapping farm practices to economic indicators

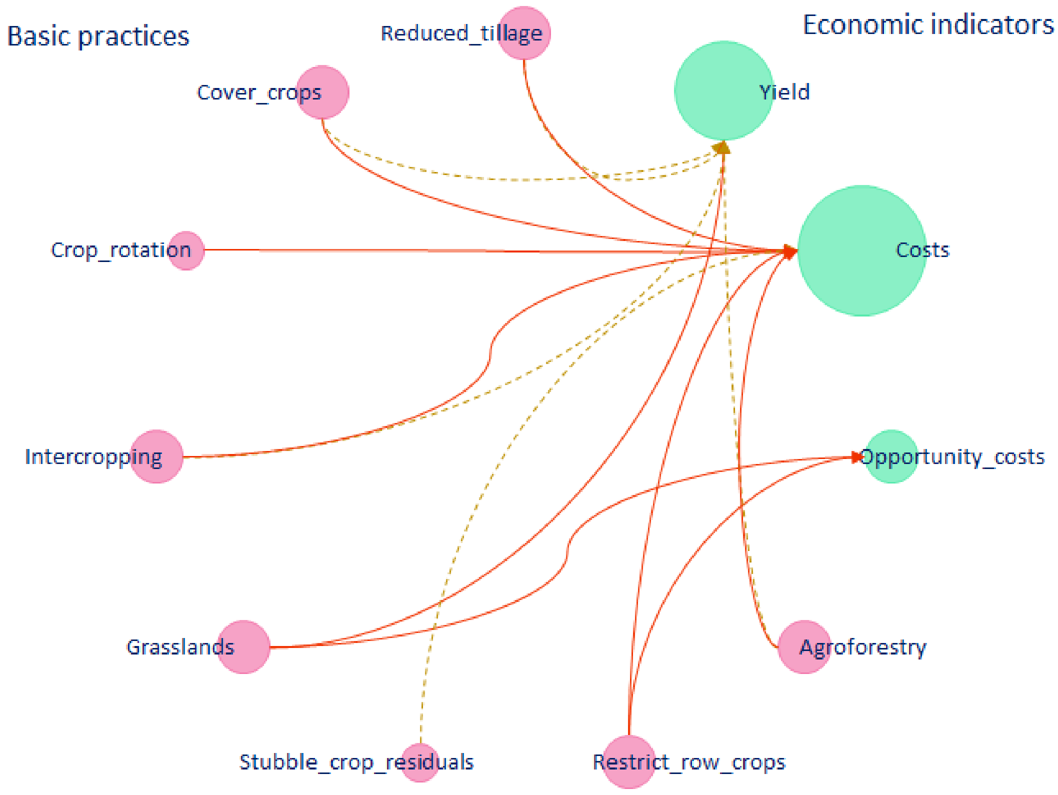
Soil protection practices entail economic costs. We therefore selected two economic indicators of interest to growers: Yield (often loss in the short run) and Costs, investment cost of machinery (e.g. for reduced tillage), as well as (and perhaps mainly) operational costs involving the use of inputs such as seeds for intercropping, fertilisers and pesticides, and labour and machinery use costs. One should also consider opportunity costs as income forgone due to restriction on the use of some crops etc. It should be noted that these are direct costs, and do not include the savings made to the public or environment through a reduction in external costs.

	Economic indicators		
Basic practices	Yield	Costs	Opportunity_ costs
Reduced_tillage	±	-	
Cover_crops	±	-	
Crop_rotation		-	
Intercropping	±	-	
Grasslands	-		-
Stubble_crop_residuals		±	
Restrict_row_crops		-	-
Agroforestry	±	-	

Table 13 Mapping economic indicators and basic soil protection practices. Source: JRC (2010), Maskell et al (2019)

	Economic indicators		
Other practices	Yield	Costs	Opportunity_ costs
Conservation_buffers	±	-	-
Terracing		-	
Sward_diversity	+	-	
Strip_cropping		-	
Ridge_tillage		±	
Contour_farming	±	±	
Subsoiling	-	-	
Delayed_manure_inc		±	
Exog_org_matter	+	-	
Less_anorg_fer	-	±	-
Less_pestic	-	±	-
Rivers_intens_restr	-		
Hedgegrow_man	±	±	
Appropriate_machinery	±	-	
Legumes_on_recult_ag_land	+		

Table 14 Mapping other soil protection practices to economic indicators. Source: JRC (2010), Maskell et al (2019)



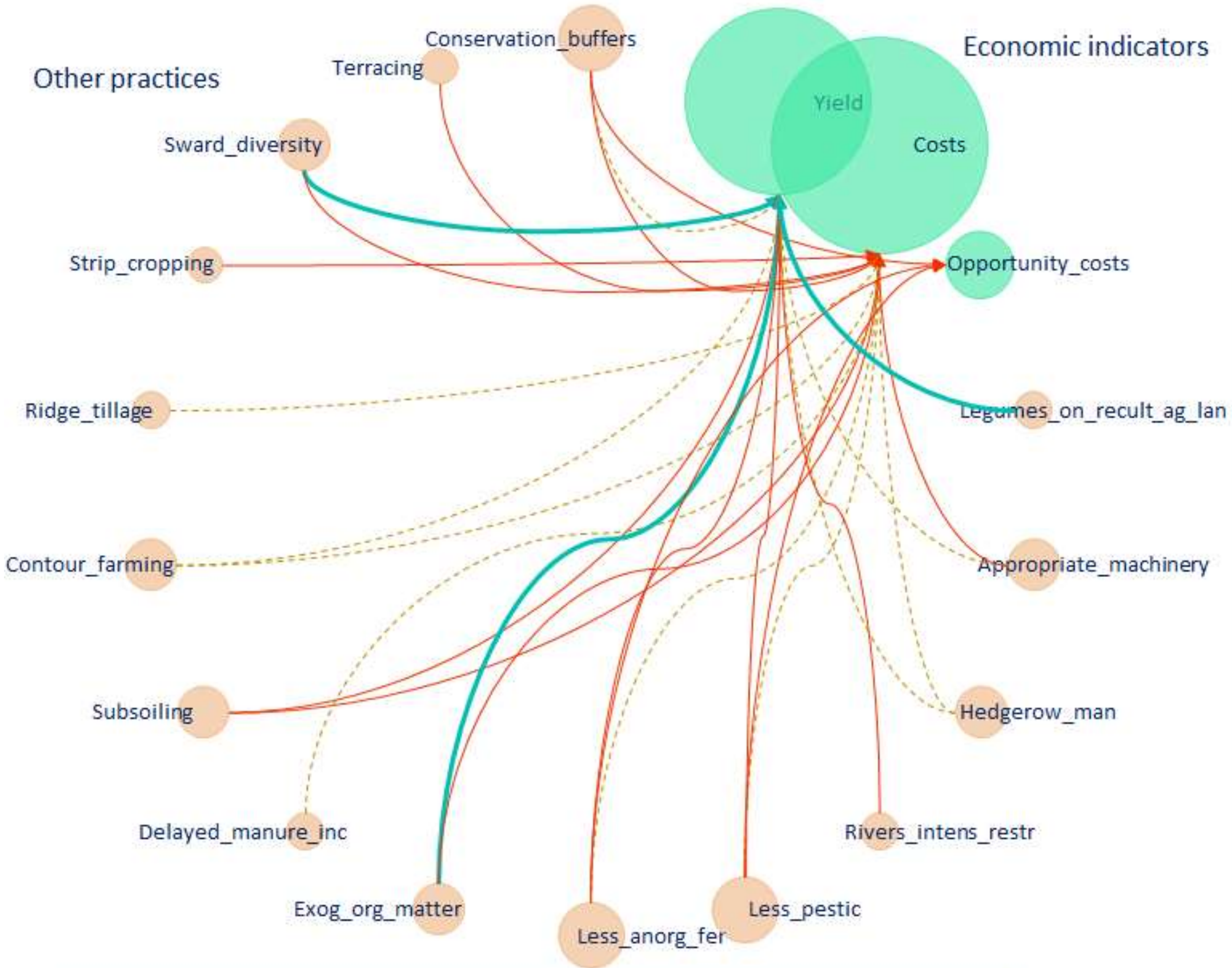
Abbreviations

Reduced_tillage = No or reduced tillage
Cover_crops = Cover crops
Crop_rotation = Crop rotation
Intercropping = Intercropping
Grasslands = Grasslands, esp. permanent, and their maintenance
Stubble_crop_residuals = Maintenance and incorporation of stubble and crop residues
Restrict_row_crops = Restrictions on growing row crops
Agroforestry = Agroforestry

Yield = Effects on crop yields in contrast to conventional practices
Costs = Effects on farm production costs (variable + fixed)
Opportunity_costs = Opportunity costs / income forgone

Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Figure 13 Mapping basic practices and economic indicators. Own elaboration based on Table 13



Abbreviations

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Terracing = Terracing
Sward_diversity = Sward diversity (≈4 species)
Strip_cropping = Strip cropping
Ridge_tillage = Ridge tillage
Contour_farming = Contour farming
Subsoiling = Subsoiling
Delayed_manure_inc = Delayed manure incorporation
Exog_org_matter = (Appropriate) Use of exogenous organic matter
Less_anorg_fer = Limited or no Fertiliser use
Less_pestic = Reduced (or no) plant protection/ pesticide use
Rivers_intens_restr = Restrictions on intensive crop production in riverside areas
Hedgerow_man = Hedgerow management
Appropriate_machinery = Appropriate use of appropriate machinery
Legumes_on_recult_ag_land = Legumes on recultivated agricultural land

Yield = Effects on crop yields in contrast to conventional practices
Costs = Effects on farm production costs (variable + fixed)
Opportunity_costs = Opportunity costs / income forgone

Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Figure 14 Mapping other practices to economic indicators. Own elaboration based on Table 14

2.8. The mapping synthesis

Given all the data and information it is possible to synthesize all of it into one overarching figure. This is presented in Figure 9, ultimately showing all the links to the MB objectives

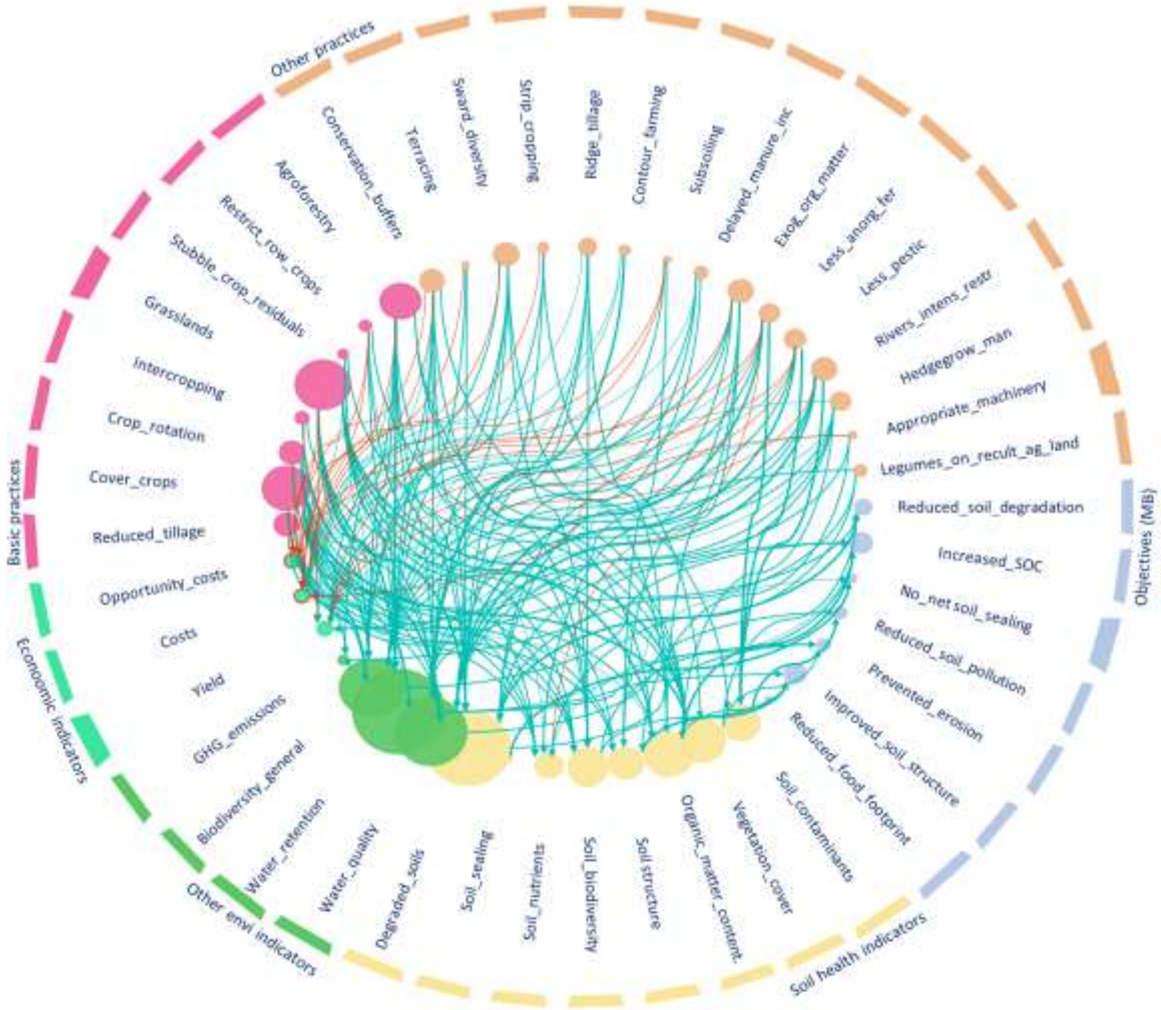


Figure 15 Overall map of practices and effects

2.9. Mapping farming systems to mission and other indicators

In this section, we first present the effects of farming systems on soil health and other environmental indicators. Then, based on these relationships we show the expected contributions of farming systems to the objectives stated by the MB.

	Soil health indicators							
Farming systems	Soil_ contaminants	Vegetation_ cover	Organic_ matter_ content.	Soil structure	Soil_ biodiversity	Soil_ nutrients	Soil_ sealing	Degraded_ soils
Organic_farming	+	+	+	+	±	+		+
Integr_crop_manag	+	+						
Conservation_agric		++	+	+	+	+		+

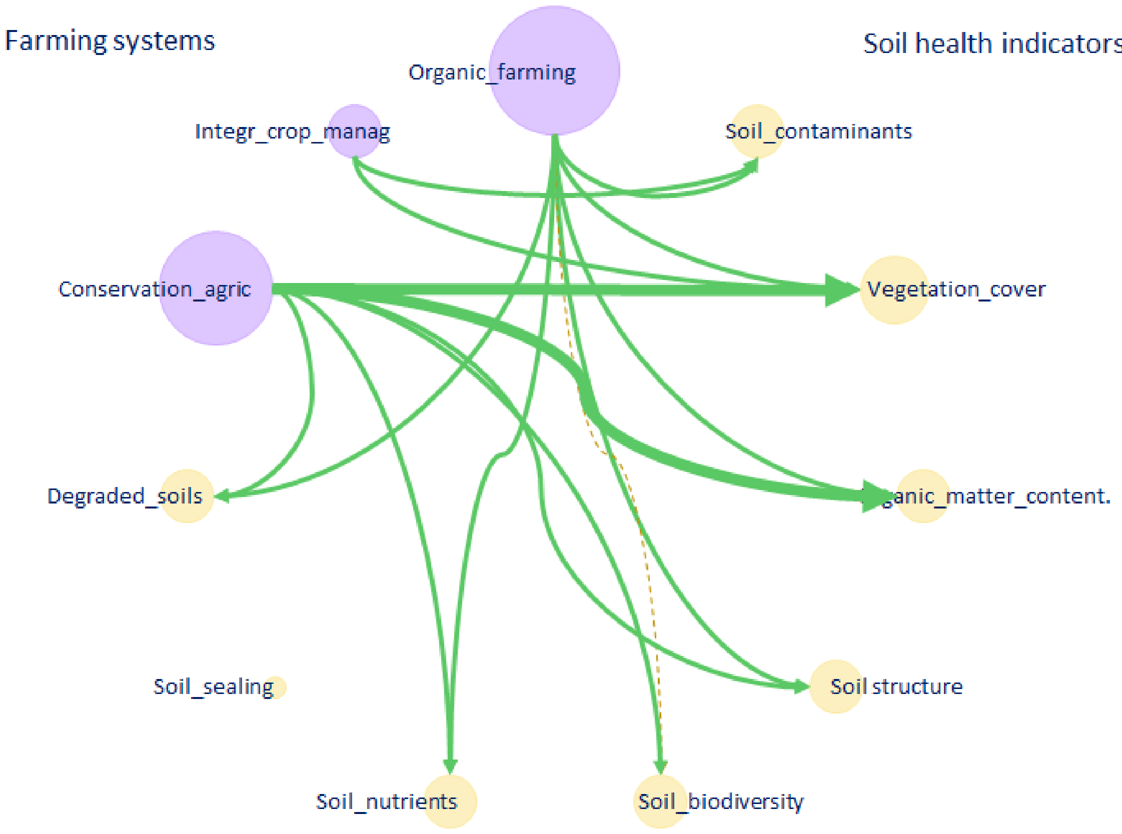
Table 15 Mapping farming systems to soil health indicators.
Source: JRC (2010), Maskell et al (2019), Agra-CEAS (2002), Marques et al. (2015)

	Other envi indicators			
Farming systems	Water_ quality	Water_ retention	Biodiversity _general	GHG_ emissions
Organic_farming	+	+	+	±
Integr_crop_manag	+	+	+	±
Conservation_agric		+	+	+

Table 16 Mapping farming systems to other environmental indicators.
Source: JRC (2010), Maskell et al (2019), Agra-CEAS (2002), Marques et al. (2015)

	Objectives (MB)						
Farming systems	Reduced_ soil_degradation	Increased_ SOC	No_net soil_sealing	Reduced_ soil_pollution	Prevented_ erosion	Improved_ soil_structure	Reduced_ food_footprint
Organic_farming	+	+		++	+	+	
Integr_crop_manag	±			++	±	+	
Conservation_agric	+	++			++	+	

Table 17 Mapping contribution of farming systems to MB objectives.
Source: JRC (2010), Maskell et al (2019), Agra-CEAS (2002), Marques et al. (2015)



Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Abbreviations

Organic_farming = Organic farming system (cretified and in transition)
Integr_crop_manag = Integrated crop management system
Conservation_agric = Conservation agriculture (reduced tillage, crop rotation, cover crop)

Soil_contaminants = Presence of soil contaminants, nutrients and excess salts and sodicity.
Vegetation_cover = Vegetation cover (general and on erosion endangered land).
Organic_matter_content. = Change of organic matter content.
Soil structure = Soil structure (compaction) and surface water infiltration
Soil_biodiversity = Soil biodiversity. Presence of functional diversity of appropriate bacteria and fungi and of soil animal communities.
Soil_nutrients = Soil nutrients (N, P, K, S, Ca], and pH
Soil_sealing = Soil sealing (annual loss of agricultural, forest and wild nature land)
Degraded_soils = The share of deeply degraded soils on agricultural and forest area (a change)

Figure 16 Mapping farming systems to soil health indicators. Own elaboration based on Table 15

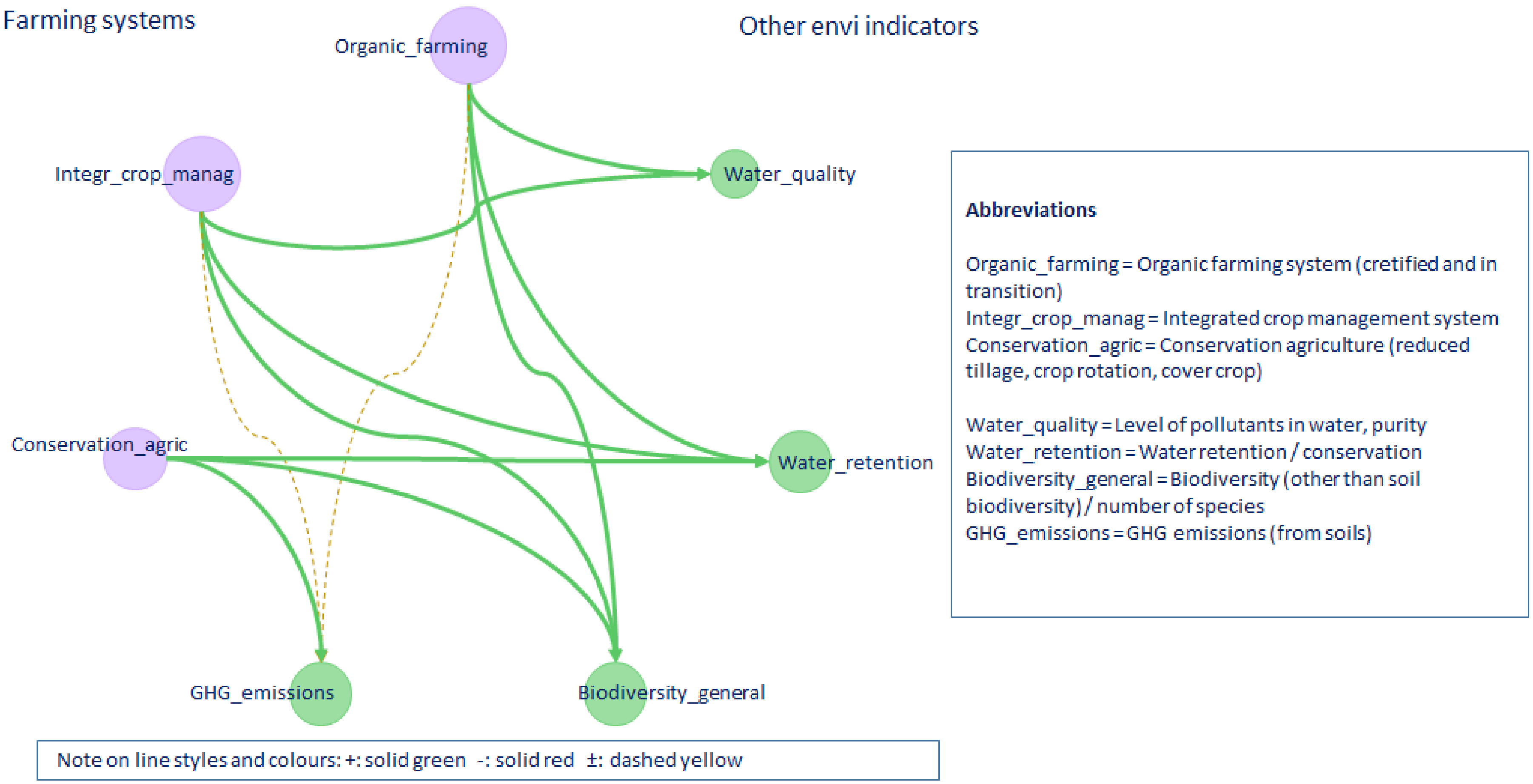
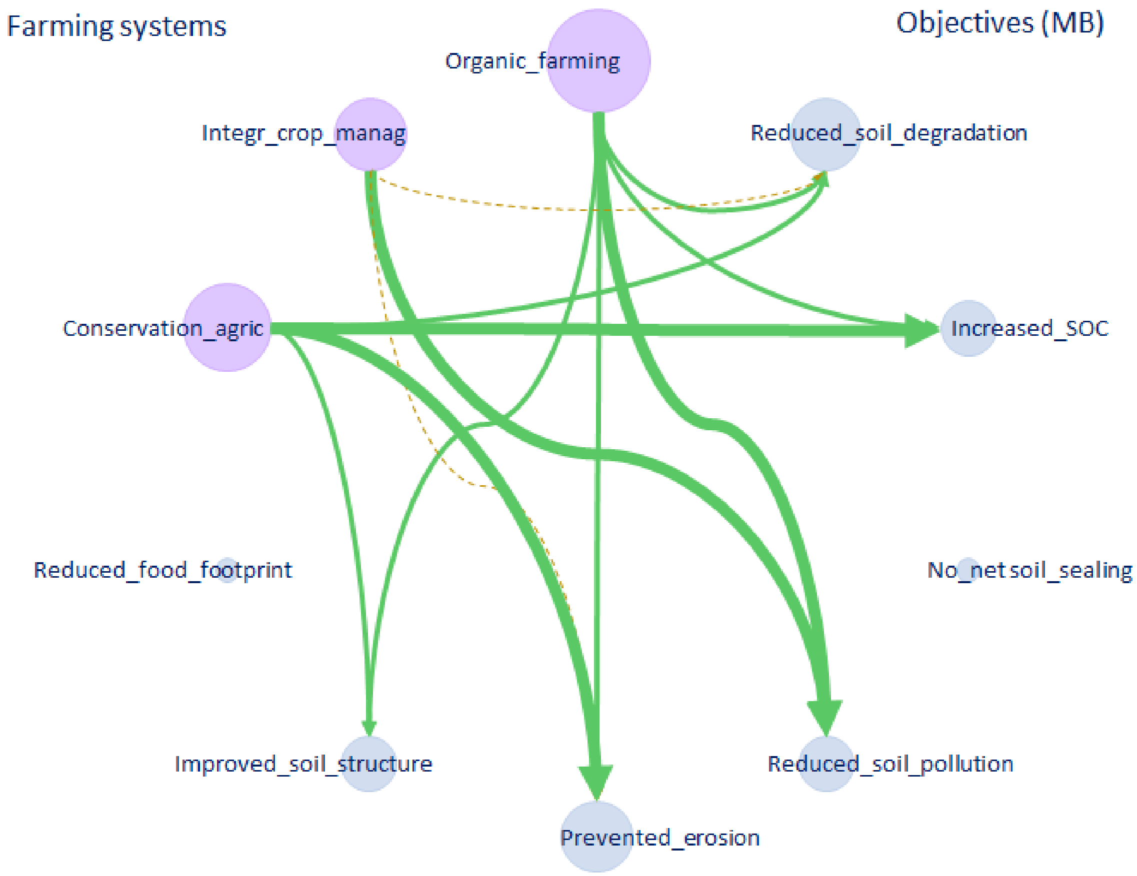


Figure 17 Mapping farming systems to other environmental indicators. Own elaboration based on Table 16



Abbreviations

Organic_farming = Organic farming system (cretified and in transition)
Integr_crop_manag = Integrated crop management system
Conservation_agric = Conservation agriculture (reduced tillage, crop rotation, cover crop)

Reduced_soil_degradation = Land degradation is strongly reduced and 50% of degraded land is restored.
Increased_SOC = High soil organic carbon (SOC) stocks are conserved and SOC content will increase by 0.1-0.4% per year. The area of peatlands losing SOC is reduced by 30-50%.
No_net soil_sealing = No net soil sealing and an re-use of urban soils increased to 50%,.
Reduced_soil_pollution = Reduced soil pollution, with at least 25% area of EU farmland under organic agriculture; a further 5-25% of land with reduced contamination risk
Prevented_erosion = Prevention of erosion on 30 to 50% of land with unsustainable erosion rates.
Improved_soil_structure = Improved soil structure, and 30 to 50% reduction in soils with high-density subsoils.
Reduced_food_footprint = 20-40% reduced global footprint of

Note on line styles and colours: +: solid green -: solid red ±: dashed yellow

Figure 18 Mapping farming systems to mission objectives. Own elaboration based on Table 17

2.10. Summary including knowledge gaps

The mapping exercise serves as an initial overview of the linkages from farm management practices to indicators and the achievement of the mission board objectives. It provides a roadmap to the development of an interdisciplinary approach to addressing the management objectives, and with the future incorporation of the private sector, NGO's and policy teams it could develop into a transdisciplinary roadmap. It is worth reflecting on a number of factors that become evident from the conduct of this exercise.

We do not address the issue of scale to any depth, but the connectedness of some interventions across the landscape will be important, especially for preventing degradation, for example by soil erosion.

We take a simplified view of the economics and don't include external costs or benefits that may arise due to the implementation of interventions.

Conflicting evidence occurs, which can make it hard to assess if an intervention has a positive, negative or neutral impact. Recent meta-analysis is helpful in determining where the weight of evidence lies, but this might not be without certain types of bias, e.g. the tendency to publish positive results.

Measures are often viewed in isolation, or within a disciplinary context, but the wider, implications for management and the economics of the practice are not dealt with.

The need for a systems approach is evident. Many research publications focus on particular management interventions, but they tend not to set the intervention within a systems context, hence emergent behaviours of combining interventions do not come through this somewhat linear analysis.

For example, important trade-offs emerge when viewed in a systems context. For example, no tillage can be appealing for improving soil structure, maintaining soil carbon in the topsoil where the microbiome needs it. No till often comes with increased use of herbicide application which can have negative impacts on water quality and the aesthetics of landscapes. Gains in fuel costs are not always made because of the need for this extra spraying. Further evidence suggests by combining mixed and cover cropping with no till, the need for pesticide use can be reduced. Such complexities can only be understood when a systems approach is used.

Hence this initial overview of the linkages between management practices, soil indicators and mission board objectives provides support for building interdisciplinary and transdisciplinary approaches. One mechanism for which is through the use of Living Labs, reviewed in the next chapter.

3. LIVING LABS AND LIGHT HOUSES

3.1. Living Labs and Light Houses: definition and criteria for the development and operation

3.1.1. Living Labs

Living Labs (LL) are defined in a variety of ways and there is no standard definition of the concept, even though the basic idea is more or less consistent across sources. The European Network of Living Labs (ENoLL) defines them as "a real-life test and experimentation environment where users and producers co-create innovations" (ENoLL 2005). According to the European Commission, Living Labs have been characterized as Public-Private-People Partnerships (PPPP) for user-driven open innovation. Trying to find the lowest common denominator, Følstad defines them as "environments for innovation and development where users are exposed to new ICT solutions in (semi) realistic contexts, as part of medium- or long-term studies targeting evaluation of new ICT solutions and discovery of innovation opportunities" (Følstad 2008: 116). Equally common is the even more general definition given by Bergvall-Kåreborn et al., defining them as a "user-centric innovation milieu built on every-day practice and research, with an approach that facilitates user influence in open and distributed innovation processes engaging all relevant partners in real-life contexts, aiming to create sustainable values" (Bergvall-Kåreborn et al. 2009: 3). What is striking about this definition is that it includes the goal of "creating sustainable values", focusing more on the user integration in the context of a sustainability orientation and the real-world development environment.

This leads to the approach of "Sustainability Living Labs" (SLL), being defined by Geibler et al. as a "research approach aimed at open socio-technical innovation processes, in which users, relevant actors in the value chains and other relevant actors in the user environment help to shape the development and application of new products, services and system solutions" (Geibler et al. 2013: 12, Geibler et al. 2014). The authors further elaborate the concept by explaining that the interactive innovation process takes place in real user environments (e.g. user observations, field tests) and/or in laboratories designed for user interaction (e.g. for prototype development) and that it is guided by "efficiency, sufficiency and consistency taking into account sustainability criteria and aims at contributing to globally and long-term generalizable, inter- and intra-generationally sustainable production and consumption patterns" (Geibler et al. 2013: 12). The definition by Liedtke et al. highlights Sustainability Living Labs as locally situated, regional, national and international infrastructures: "We define a Sustainable Living Lab as a locally based regional, national and international infrastructure set-up to enable innovation processes in which users and value chain-relevant actors actively participate in development, testing and marketing phases. Interactive innovation processes take place gradually in users' real life surroundings (user observation, field tests) and user interaction laboratories (e.g. for prototyping). An SLL, led by sustainability criteria, aims to contribute to global and universally applicable patterns of production and consumption, including the actor-integrated development of business cases, enabling transition processes to be marketed to companies and users."

Key characteristics that are reflected in all quoted definitions therefore are the participatory involvement of users, even though the various definitions do reveal differences in the way in which users are to be included, as well as the common reference to experimental concept development and open idea generation to identify new insights and unexpected usage practices of products and services. The evaluation, named as a central component of Living Labs, is understood as a prototypical implementation together with users. In contrast, the aspect of co-creation is only addressed in the ENoLL definition, by Bergvall-Kåreborn et al (2009), Geibler et al (2013) and Liedtke et al (2015). Further differences can be found in the definitions with regard to the type of laboratory and the research context. While ENoLL, Bergvall-Kåreborn et al. (2009), Geibler et al. (2013) and Liedtke at al. (2015) stress the importance of real-world use environments, Følstad (2008) speaks of "(semi) realistic contexts". Since the real-world usage context is already a prerequisite in the project, it plays a central role. Accordingly, the real-world environments of the users and/or the laboratories designed for user interaction are to be included as key categories. Living Labs are therefore understood as a research approach in which users and, if applicable, other stakeholder groups are integrated early and continuously into the innovation process and are involved in the development, application and evaluation of innovative products, services and product service systems in real contexts.

To sum it up, the European Network of Living Labs highlights four main activities a Living Lab employs (EnoLL 2005):

- Co-Creation: co-design by users and producers
- Exploration: discovering emerging usages, behaviors and market opportunities
- Experimentation: implementing live scenarios within communities of users
- Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria

Følstad (2008) stresses similar characteristics to EnoLL (2005): (1) to gain insights into the use of new ICT solutions, (2) to evaluate and validate new solutions together with users, (3) to experience and experiment with ICT solutions in user contexts and (4) to evaluate with users in the medium to long term. Very apparent is the focus on the information and communications technology (ICT) area, that is not shared in every definition of Living Labs. The ICT-related definitions can be attributed to the fact that, according to Eriksson et al., the term Living Lab was coined at the MIT Media Lab and was originally conceived as an instrument to study users in their interaction with new ICT-based artifacts in a real-world environment (Eriksson et al. 2005). In recent years, the "Living Labs" approach has gained increasing attention in various fields, including sustainability and transformation research (Liedtke et al. 2012a; Ley et al. 2015). Compared to a Light House Project, a Living Lab is still in the "trial phase" and its focus is thereby not in the same way as a Light House on acting as a good example for others to follow. The aim is rather to achieve innovative results in a participatory way with different actors.

Apart from the different definitions of a Living Lab methodology, the concrete practical implementation and establishment of a Living Lab approach can vary greatly from project to project. Therefore, before mentioning some practical examples of Living Labs, the different forms of a Living Lab will first be described in a morphological box (Geibler et al 2013):

Characteristics	**Possible specifications**			
Classification of the research settings (or laboratory)	Real laboratory (semi-realistic or real world, e.g. in relation to a model city, region or building)	Real world (real environment, e.g. in relation to a model city, region or building)		
Empirical approach	Qualitative methods of empirical social research (such as interviews, surveys,	Quantitative methods of empirical social research	Experiments, field tests or measurement (e.g. also tracking)	

	diary studies, observations)			
Creative, design-oriented approaches	prototype development ("prototyping"), incremental or evolutionary development	Use/application scenario, personas, ...	Participatory design methods (such as creative, design or innovation workshops)	
Role of user integration (along the definitional provisions)	Co-Creation	Context exploration	Experiment	Evaluation
Socio-technical focus	Decision support system	ICT	Acceptance	
Field of application	Production and Consumption	Urban and regional development		
Market dimension	Market acceptance	Distribution		
Dimension of use	User behaviour (e.g. technology acceptance, appropriation studies)	Rebound effect	Obsolescence	
Involved stakeholders	Supplier (industry or service provider e.g. designer, producer)	Users/end users (e.g. citizens)	Research / Science	Politics or actors in the value chain

Table 18 Forms of Living Lab. Source: based on Geibler et al 2013

Living Labs are generally understood as an infrastructure that enables and fosters a user-centred research methodology (Eriksson et al. 2005). According to a general understanding, the Living Lab approach comprises a user-centred, real-world research environment in which not only science, business and organisations jointly carry out research and development, but above all the user themselves take an active role within the innovation processes (Følstad 2008, Niitamo et al. 2006).

As an example, the Interreg program across the EU is one vehicle ideally placed to develop the Living Lab concept, for Living Labs with a greater policy component. The purpose of Interreg Europe is to, "help regional and local governments across Europe to develop and deliver better policy. We create an environment and opportunities for sharing solutions and policy learning. We aim to make sure that government investment, innovation and implementation efforts all lead to integrated and sustainable impact for people and place.[30]"

"Today, the EU's emphasis is very much on paving the way for regions to realise their full potential – by helping them to capitalise on their innate strengths while tapping into opportunities that offer possibilities for economic, social and environmental progress." The emphasis being on:

- Reducing disparities between regions
- Transnational Cooperation as a method
- Innovation, Low carbon and Resource and materials efficiency

Challenge 3 of the 6 identified by Interreg North West Europe (NWE, Interreg NWE, 2020) [31]focuses on: Resource and materials efficiency which is where the FABfarmers project sits.

'North-West Europe must lead the way in the smart use of water, land, air and materials, considering its high population density and growing environmental problems. The NWE countries are among the highest resource consumers in the EU. The challenge is to further decouple economic growth from material consumption and to make better use of waste materials and energy from waste.

To tackle this challenge, we need to:

- Implement common transnational strategies on use of resources, increase of resource efficiency and waste management;
- Promote eco-innovation as a means of contributing the de-materialisation of society;
- Reduce the dependence on imported material resources;
- Address the opportunities presented by the use of waste for raw material recovery and energy production and opportunities for new material development from waste.

Therefore, the aims of the Interreg program and its specific components are aligned with the aims of the Living Labs concept as defined by Geibler et al. (2014), "Living Labs for Sustainable Development aim to integrate users and actors for the successful generation of low-resource innovations in production-consumption systems."

3.1.2. Light Houses

There is no unified definition of a Light House project (LH). In generally a Light House project serves as a good example for others to learn from:

- A Light House project is a short-term, well defined, measurable project that serves as a model - for other similar projects within a broader range of projects. The concept mainly originated from the digital field in which it "focuses on implementation, fast delivery and creating a positive culture for digital transformation" (Williams 2017). There it serves as a model for similar projects within the broader digital transformation initiative.
- "A Light House project is a small-scale but big-picture project. It's like a beacon for future digital transformation and development. With this tried-and-tested approach, you can turn ideas into real value (…)" (Sonin Agency 2019).
- In a broader context, Light House projects are used to develop the scientific basis for multidisciplinary transition- and innovation research and an accompanying communication program (Geibler 2014).

Some key features and characteristics of a Light House project are (Sonin Agency 2019):

- a progressive nature,

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[30] Interreg 2020. https://www.interregeurope.eu/about-us/what-is-interreg-europe/

[31] Interreg NWE, 2020. https://www.nweurope.eu/about-the-programme/what-is-interreg-nwe/

- fast delivery and
- adaption to new ideas, a specific problem to address and important, a clear and easily understood metrics.

This means it should have a clear and easily understandable value to potential successors as well as takeaways for all the different stakeholders. The benefit and success of the project should always be evident. Furthermore, Light House projects should demonstrate use potentials, initiate innovations and demonstrate examples (Geibler 2014).
From a more research or economically oriented perspective, "Light House projects put the focus on strategic objectives with a view to developing practical solutions from which economies (…) can benefit." (Fraunhofer-Gesellschaft). "The topics these projects address are geared towards economic requirements. By pooling their expertise and involving industrial partners at an early stage, the Fraunhofer Institutes involved in the projects aim to turn original scientific ideas into marketable products as quickly as possible." (Fraunhofer-Gesellschaft).

With regards to the agricultural sector, the Fraunhofer Light House project "COGNAC" is conducting joint research on basic principles for producing agricultural products "that are as environmentally friendly and resource-saving as they are highly efficient" (Fraunhofer IESE). The project aims at automatically collect data about complex interrelations in farming and, based on that, to support decision-making processes in the value network and it involves pilot applications on test fields, another typical feature of Light House projects.

3.2. Case Studies

3.2.1. Living Laboratories

3.2.1.1. Living Lab example of arable and livestock farming

European Union Interreg program and FAB-farmers project as an example of Living Lab for soil health and food https://www.interregeurope.eu/about-us/what-is-interreg-europe/

FAB-farmers is an Interreg project of the European Union that aims to reduce the reliance on external inputs to farming by encouraging the use of methods and interventions that increase the farm's **Functional AgroBiodiversity (FAB).** The project recognises the agricultural sector as a production consumption industry that needs to continue moving towards lower resource use and working with nature as much as possible while maintaining food production in a sustainable way. It recognises the urgent need for increased resource efficiency in farming systems (fertilizers, pesticides, water, fuel, machinery, antibiotics,…) to make the transition to more circular agro-ecosystems. As a part of this, maintaining natural capital and the delivery of ecosystem services is seen as an important part of farm husbandry. 'FABulous Farmers' aims to accelerate the adoption and implementation of functional agrobiodiversity (FAB) by farmers and other land managers. FAB refers to farm management practices that support and enhance elements of biodiversity (eg. pollinators, natural enemies, soil fauna,...) for their role in providing ecosystem services (increased pollination, soil fertility, water conservation, biological pest and disease control). Thus working with nature, as far as possible, to deliver benefits for farmers, society and the environment while endeavouring to maintain yields. It uses a systems thinking approach, through the innovative use of targeted measures, designed to maximise benefits from nature in the farming process.

Functional agrobiodiversity interventions include: reduced tillage; mixed crops/rotation; cover crops; organic matter input; modify manure quality; agroforestry; hedgerow management; field margin management; reduction in the use of plant protection products; semi-natural landscape elements (provide habitat).

The project is a consortium with an inner partner circle of farm advisory groups, NGO's, research centres and university researchers. This is surrounded by a circle of sub-partners from industry, policy and NGO's, enclosed by a further circle of 'first adopters', linked into the wider network of growers in the farming industry. It uses an area-based approach for the joint development, testing and adoption of FAB solutions, with evaluation in terms of ecological functioning, resource use and economic sustainability. 12 pilot regions, varying in size and scope, form a fundamental delivery network throughout the NWE region of the EU to deliver 3 objectives:

1. *Collect, deepen and share knowledge on FAB*: This is achieved through analysis of the evidence base, contribute to the knowledge base, in this case using the WOCAT database on sustainable land management technologies, kitchen table talks, reviewing tools, methods and approaches that can be used to aid growers with systems thinking such as farm sustainability tools. Assess suitability of areas for the adoption of interventions and review decision support tools.
2. *Widen uptake of FAB by farmers through demonstration*: Create learning and demonstration networks that can be used for knowledge exchange, co-design and innovation development. Demonstrate examples, test monitoring and learning approaches. Test sustainability tools, decision support tools and monitoring approaches using open platforms where possible that can inform on farm decisions.
3. *Embed FAB in the local society*: by engaging with communities, working with citizen science groups for example. Testing of citizen science tools and networks to bring society and farming together.

The project exemplifies the European Union approach to Public–Private–People Partnerships (PPPP) for user-driven open innovation to enhance resource use efficiency using 'living lab' approach.

3.2.2. Lighthouse projects

3.2.2.1. Light House example of arable and livestock farming

A good example of Light House projects in the agricultural sector is the Lighthouse Farm Network, a global network of Light House farms that brings together exemplary farms and foodscapes from around the world "that have found radical solutions to address the sustainability challenges we currently face" (Global Network of Lighthouse Farms 2020). The lighthouse farms in that network are existing and commercially viable farms in the real world which are "positive deviants" and are "already in 2050" in terms of providing sustainably produced food and ecosystem services (Global Network of Lighthouse Farms 2020). Furthermore, they "demonstrate what can be achieved", are "examples of specific aspects of sustainable production" and can serve as real-life experimental farms "to advance our scientific understanding of the principles and practices of sustainable production in contrasting environments" (Wageningen University & Research 2017a). "Together, they create a global outdoor classroom and laboratory on sustainable food security and for tomorrow's farms and foodscapes". The main goals are:

1. Providing opportunities for engagement and collaboration with farmers, stakeholders, industry and policy makers,
2. Facilitating valuable shared learning between contrasting "Light House systems" and
3. Providing a platform to anchor international collaborations.

A practical project or farm that can serve as an example is the La Junquera farm, an organic farm and village that is being transformed into a beacon of regenerative agriculture in Southern Spain. Being located at the border of the desert, it faces many challenges related to soil erosion, water shortages and other conditions. It focuses on building silt traps, swales, composting, limited tilling, and the restoration of natural areas. "These

practices not only help to reduce erosion, improve fertility and increase water infiltration but also help to increase biodiversity." (Global Network of Lighthouse Farm 2020).
Another example would be the ERF BV in the Netherlands conducting strip cropping farming and investing in a healthy, fertile Flevoland soil. In Austria, the organic GRAND FARM applies low-tillage methods to maintain and improve the soil. On-farm research projects support the development of agroforestry, the livestock sector and the market garden and the GRAND FARM is a "frontrunner in advancing vermiculture and vermicomposting – composting with the help of earthworms" (Wageningen University & Research 2017b).

In order to have an impact on global agriculture, the Light House projects involve researchers and students in engaging with local communities of actors "to identify and understand barriers to transformation, and either chart a path to removing these, or iteratively redesign the Light Houses to be compatible with local decision making" (Wageningen University & Research 2017a).

3.2.2.2. Light House example of forest systems

An example for an **agroforestry** project is the research and model project in the Löwenberger Land from the University for Sustainable Development in Eberswalde. It is located about 50 km north of Berlin and the experimental area comprises approximately 30 hectares (approx. 10 hectares each of agroforestry, zero area, short rotation plantation) of an agriculturally used area (DeFAF 2020). Students from all faculties of the university work together in the project, which was offered for the first time in the winter semester 2017/2018 and represents an innovative form of teaching and learning in which research is carried out on an interdisciplinary basis. The aim and motivation is to use the findings gained to show how a complex agroforestry system that counteracts compaction, evaporation, impoverishment, loss and sealing can be structured. The project area is meant to have a radiating effect and to encourage imitation.
The agroforestry system with strips of different tree species, a total of eight rows of trees on 10 hectares of land with 340 valuable woods such as wild pear, red oak and tree hazel as well as around 500 fast-growing willows, provides protection against wind and water erosion in particular; an effect which it can already begin to notice by planting roadside trees (Pflanzenforschung.de 2020). The trees are intended to slow down the wind and thus preserve the moisture in the soil longer. Further benefits are expected to be increased soil fertility, less wind erosion, lower temperatures due to the trees' shadows and increased biodiversity on agricultural land. The landscape will also become more attractive and farmers will be able to market the wood from the trees, for example as wood chips for biomass power plants. In order to change the legal framework for agroforestry subsidies, the participants are also counting on the impact of their model project. They hope that they will be able to convince political decision-makers from nearby Berlin of this sustainable use of land by means of excursions.
Following key features and characteristics of a Light House project are visible in this case:

- a progressive nature
- adaption to new ideas, a specific problem to address and important, a clear and easily understood metrics
- model - for other similar projects within a broader digital transformation initiative
- small-scale but big-picture project
- basis for multidisciplinary transition- and innovation research

3.2.2.3. Light House example of urban, peri-urban fringe

Another project that can be described as a lighthouse is focusing on **urban farming**. The goal of the "Frisch vom Dach"-project, also located in Berlin, was to build the world's largest aquaponic roof farm on the roof of the Berliner Malzfabrik in order to practice sustainable agriculture and fish breeding all year round (Gabot 2011). The mission was the construction, planning and operation of aquaponic farms in the city with the vision of

a year-round organic farming with a neutral CO2 balance. Agriculture and fish breeding in the DACHFARM should contribute to sustainable nutrition through minimal water consumption and the elimination of transport routes (Gabot 2011). "It is hardly a logical spot for a farm, but three Berliners have earmarked a massive former factory roof for an unusual urban agriculture venture. The sustainable set-up will produce both vegetables and fish for local residents and could be a model for future city farms as the world continues to urbanize" (Smee 2011).
The project that was initiated nearly a decade ago can be seen as a Light House that certainly inspired many of the urban framing and gardening projects that are being carried out today.
Light House farms are considered as a potential solution to the imminent challenges global agriculture faces, arising i. a. from a growing world population and an increasing demand for food that exceeds the planetary boundaries and can thus "not be sustained indefinitely" (Wageningen University & Research 2017a). The 'grand challenge' being to transform global farming systems so that they simultaneously contribute to food security, maximize resource use efficiency, ensure stability and resilience, minimize environmental impact and contribute to social justice. "This transformation requires the design of new future farming systems that meet the objectives for a range of soils, climates, cultures and local conditions" (Wageningen University & Research 2017a).
Some key features and characteristics of a Light House project are visible in this case:

- adaption to new ideas, a specific problem to address and important, a clear and easily understood metrics
- model - for other similar projects within a broader digital transformation initiative
- small-scale but big-picture project

3.3. Criteria for the development and operation of Living Labs and Light Houses

Based on the review and practical experience from the group we identify, compare and propose a set of basic criteria for the development and operation of Living Labs.

Feurstein et al., (2008) opined that by definition a Living Lab is a network, a single Living Lab network has multiple stakeholders and has the following components:

- Must be a network
- Must contain multiple stakeholders
- Real life research environment
- Mission to tackle innovation problems

According to the European Network of Living Labs (ENoLL) a Living Lab has four main activities (Leminen et al., 2012)**:**

- Co-creation: co-design by users and producers
- Exploration: discovering emerging usages, behaviours and market opportunities
- Experimentation: implementing live scenarios within communities of users
- Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria

More recently, Westerlund et al (2018)[32] have identified 9 key constructs around which Living labs develop that are summarized from Table 1 in their article below:

[32] Westerlund, M., Leminen, S. and Habib, C., 2018. Key constructs and a definition of living labs as innovation platforms. *Technology Innovation Management Review*, *8*(12).

Construct	Definition
Objective	The positive impact that the innovation output is expected to produce.
Governance	A structural or procedural model by which decisions for the innovation projects, process or organisation are made.
Openness	Mindset of the organisation that is reflected in their level of openness and collaboration
Stakeholders	Entities that add value to the Living Lab
Funding	The means by which the Living Lab financially supports its innovation activities
Values	The benefits the stakeholders gain from their membership and participation within the Living Lab
Communication	The channels, technology and techniques used to network stakeholders for information exchange
Infrastructure	The necessary resources and specialized equipment required to carry out the innovation activities.
Methods	The procedural steps used for the inception, development and deployment of innovation.

Table 19 Key constructs for Living Labs from Westerlund et al (2018)[33]

Drawing this together we propose the following represent key criteria for Living Labs:

Objective:

- To support co-creative, human-centric and user-driven research, development and innovation in order to better cater for people's needs.

Structure:

- Established as a network
- Include multiple stakeholders
- Stage a real-life research environment
- Have a well-defined mission to tackle innovation problems

Activities

- Co-creation: co-design by users and producers
- Exploration: discovering emerging usages, behaviours and market opportunities
- Experimentation: implementing live scenarios within communities of users
- Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria

Ambition:

- Open innovation oriented: a governance based on facilitating innovation by actively involving people in the ecosystem to search for value, even before it is identified as valuable.
- A challenging and interdisciplinary program: at the heart of the future Living Labs is a program of challenging, concrete projects that enable a joint learning process and bond people from different backgrounds.

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[33] Westerlund, M., Leminen, S. and Habib, C., 2018. Key constructs and a definition of living labs as innovation platforms. *Technology Innovation Management Review*, *8*(12).

- Jointly developing sustainable platforms: Continuous development of open, multipurpose democratised platforms (a mash-up of data, services and products) to enable a diversity of propositions.
- Co-learning in an ambitious ecosystem: An ecosystem of ambitious people who understand the challenges and are willing to contribute with the prospect of being able to benefit from the innovation.
- Creating a social and physical 'meeting place': An interactive place where designers, developers, entrepreneurs and researchers meet and co-create real solutions for real people in real-life settings.
- Boosting prosperity and welfare in the region: A co-creative, experimental environment that contributes to the welfare and well-being in the region by creating new businesses (jobs) and a vibrant economy.

4. References

References Section 1

Adhikari, K, Hartemink, AE. 2016. Linking soils to ecosystem services — A global review. Geoderma 262: 101-111.

Bünemann, EK, Bongiorno, G, Bai, Z, Creamer, RE, De Deyn, G, de Goede, R, Fleskens, L, Geisen, V, Kuyper, TW, Mäder, P, Pulemann, M, Sukkel, W, van Groeningen, JW, Brussard, L. 2018. Soil quality – a critical review. Soil Biology and Biochemistry 120:105-125.

EEA. 2016. European forest ecosystems — State and trends. European Environment Agency. 123 pp.

European Commission (EC). "A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system" (COM(2020) 381 final)

European Commission (EC). „Thematic Strategy for Soil Protection" (COM(2006)231)

European Commission (EC). „Towards a Thematic Strategy for Soil Protection" (COM(2002)179)

European Commission (EC). European Green Deal: https://ec.europa.eu/info/publications/communication-european-green-deal_en

FAO http://www.fao.org/agroecology/home/en/

FAO. 2016. Global Forest Resources Assessment 2015 - How are the world's forests changing? Second edition. FAO. Rome

Forest Europe. 2015. State of Europe's Forests 2015. Ministerial Conference on the Protection of Forests in Europe. Madrid

Friel S., Schram A and Townsend B. 2020. The nexus between international trade, food systems, malnutrition and climate change. Nature Food 1, 51–58. www.nature.com/natfood.

Garnett, T, Appleby, MC, Balmford, A, Bateman, IJ, Benton, TG, Bloomer, P, Burlingame, B, Dawkins, M, Dolan, L, Fraser, D, Herrero, M, Hoffmann, I, Smith, P, Thornton, PK, Toulmin, C, Vermeulen, SJ, Godfray, HCJ. 2013. Sustainable Intensification in Agriculture: Premises and Policies. Science 341: 33-34.

Glaesner N, Helming K, De Vries W. 2014. Do current European policies prevent soil threats and support soil functions? Sustainability 6, 12, 9538-9563

Helming K, Daedlow K, Paul C, Techen A, Bartke S, Bartkowski B, Kaiser DB, Wollschläger U, Vogel HJ. 2018. Managing soil functions for a sustainable bioeconomy – Assessment framework and state of the art. Land Degradation & Development 29:3112-3126.

HLPE. 2017. Sustainable forestry for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome

IPES-Food. 2016. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems. http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

IPES-Food. 2016. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems. http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

IPES-Food. 2017. Too big to feed: Exploring the impacts of mega-mergers, concentration, concentration of power in the agri-food sector. www.ipes-food.org

Mission Board Soil Health and Food. 2020. Caring for Soil is Caring for Life.

OECD. 2012. OECD Environmental Outlook to 2050, OECD Publishing. http://dx.doi.org/10.1787/9789264122246-en

Paul, C; Kuhn, K; Steinhoff-Knopp, B; Weißhuhn, P; Helming, K. 2020. Towards a standardisation of soil-related ecosystem service assessments. Eur. J. Soil Sci. 2020, accepted article doi:10.1111/EJSS.13022

Poux X, Aubert P-M. 2018. Une Europe agroécologique en 2050: une agriculture multifonctionnelle pour une alimentation saine. Enseignements d'une modélisation du système alimentaire européen, Iddri-AScA, Study N°09/18, Paris, France, 78 p

Robinson, D.A., Fraser, I., Dominati, E.J., Davidsdottir, B., Jonsson, .O.G., Jones, L., Jones, S.B., Tuller, M., Lebron, I., Bristow, K.L., Souza, D.M., Banwart, S. & Clothier, B.E. 2014. On the Value of Soil Resources in the Context of Natural Capital and Ecosystem Service Delivery. Soil Science Society of America Journal, 78, 685-700.

Rockström J *et al*. 2009. A safe operating space for humanity. Nature 461, 472–475. doi: 10.1038/461472a; pmid: 19779433;

Schulte, RPO, Creamer, RE, Donnellan, T, Farrelly, N, Fealy, R, O'Donoghue, C, O'hUallachain, D. 2014. Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. Environmental Science & Policy 38: 45-58.

Steffen W *et al.* 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347, 1259855 (2015). DOI: 10.1126/science.1259855 Downloaded from http://science.sciencemag.org/ on March 14, 2017

Techen, A. Helming, K., Brüggemann, N., Veldkamp, E., Reinhold-Hurek, B.,; Lorenz, M., Bartke, S., Heinrich, U., Amelung, W., Augustin, K., Boy, J., Corre, M., Duttman, R., Gebbers, R., Gentsch, N., Grosch, R., Guggenberger, G., Kern, J., Kiese, R.,; Kuhwald, M., Leinweber, P., Schloter, M., Wiesmeier, M., Winkelmann, T., Vogel, H.J. 2020. Soil research challenges in response to emerging agricultural soil management practices. Advances in Agronomy 161:179-240

Tittonell, P. 2014. Ecological intensification of agriculture—sustainable by nature. Current Opinion in Environmental Sustainability 8: 53-61.

UN Environment. 2019. Global Environment Outlook – GEO-6: Healthy Planet, Healthy People. Nairobi. DOI 10.1017/9781108627146.

UNECE/FAO. 2011. European Forest Sector Outlook Study II. Geneva. 111 pp.

UNECE/FAO. 2015. Forests in the ECE Region - Trends and Challenges in Achieving the Global Objectives on Forests. ECE/TIM/SP/37. 212 pp.

Vogel HJ, Bartke S, Daedlow K, Helming K, Kögel-Knabner I, Lang B, Rabot E, Russell D, Stößel B, Weller U, Wiesmeier M, Wollschläger U. 2018. A systemic approach for modeling soil functions. SOIL 4:83–92.

Willett W et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. Published online January 16, 2019 http://dx.doi.org/10.1016/S0140-6736(18)33179-9

References Section 2

Agra-CEAS (2020) Integrated Crop Management Systems in the EU. Amended Final Report for European Commission (DG Environment). https://ec.europa.eu/environment/agriculture/pdf/icm_finalreport.pdf

JRC (2010) Final report on the project 'Sustainable Agriculture and Soil Conservation (SoCo)' https://esdac.jrc.ec.europa.eu/content/final-report-project-%E2%80%98sustainable-agriculture-and-soil-conservation-soco%E2%80%99

Marques, F., Perdiago, A., Gomez-MacPherson, H., Basch, G. Mavridis, A., Sarno, G. (2015) Conservation Agriculture: A promising approach to invert SOM decline in the Mediterranean region. Minipaper EIP AGRI. https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/fg5_mp_om_conservationagriculture_2015_en.pdf

Maskell, L. Norton, L., Alison, J., Reinsch S., Robinson D.A., 2019 Review of current methods and approaches for simple on farm environmental monitoring of FAB solutions.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. and Alewell, C., 2015. The new assessment of soil loss by water erosion in Europe. Environmental science & policy, 54, pp.438-447.

References Section 3

Living Labs

Bergvall-Kåreborn, B., Ihlström Eriksson, C., Ståhlbröst, A., Svensson, J., (2009): A milieu for innovation– defining living labs.

ENoLL (2005): European Network of Living Labs. What is a Living Lab? Available at http://www.observatorioabaco.es/en/post_conocimiento/european-network-of-living-labs-enoll.

Eriksson, M., Niitamo, V.P., and Kulkki, S. (2005): State-of-the-art in utilizing Living Labs approach to user-centric ICT innovation–a European approach [online]. white paper. Available from:

http://www.vinnova.se/upload/dokument/verksamhet/tita/stateoftheart_livinglabs_eriksson2005.pdf

Følstad, A. (2008): Living labs for innovation and development of information and communication tech-nology: a literature review.

Geibler, J. v.; Erdmann, L.; Liedtke, C.; Rohn, H.; Stabe, M.; Berner, S. et al. (2013): Living Labs für nachhaltige Entwicklung – Potentiale einer Forschungsinfrastruktur zur Nutzerintegration in der Entwicklung von Produkten und Dienstleistungen. Wuppertal Spezial 47.Wuppertal Institut für Klima, Umwelt und Ener-gie.

Geibler, v. J., Erdmann, L., Liedtke, C., Rohn, H., Stabe, M., Berner, S., Leismann, K., Schnalzer, K., Kennedy, K., (2014). Exploring the potential of a German Living Lab research infrastructure for the development of low resource products and services. Resources 2014, 575-598.

Interreg 2020. https://www.interregeurope.eu/about-us/what-is-interreg-europe/

Interreg NWE, 2020. https://www.nweurope.eu/about-the-programme/what-is-interreg-nwe/

Ley, B., Ogonowski, C., Mu, M., Hess, J., Race, N., Randall, D., Rouncefield, M.; Wulf, V. (2015): At home with users: a comparative view of Living Labs. Interacting with Computers, 27(1), 21-35.

Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., & Grinewitschus, V. (2015): User-integrated innova-tion in Sustainable LivingLabs: an experimental infrastructure for researching and developing sustainable product service systems. Journal of Cleaner Production, 97, 106-116.

Liedtke, C.; Welfens, M. J.; Rohn, H.; Nordmann, J. (2012a): LIVING LAB: User-driven innovation for sustainabil-ity, International Journal of Sustainability in Higher Education, Vol. 13 Iss: 2, pp.106 – 118.

Westerlund, M., Leminen, S. and Habib, C., 2018. Key constructs and a definition of living labs as innovation platforms. Technology Innovation Management Review, 8(12).

Light Houses

Deutscher Fachverband für Agroforstwirtschaft (DeFAF) e.V. (2020): ACKERBAUM – Das Agroforst Forschungs- und Modellprojekt im Löwenberger Land von der Hochschule für nachhaltige Entwicklung in Eberswalde. Available at https://agroforst-info.de/portfolio-item/ackerbaum/.

Fraunhofer-Gesellschaft: Lighthouse projects – Reducing Time to Market. Available at https://www.fraunhofer.de/en/research/lighthouse-projects-fraunhofer-initiatives/fraunhofer-lighthouse-projects.html.

Fraunhofer-Institut für Experimentelles Software Engineering IESE: Fraunhofer-Leitprojekt "Cognitive Agriculture". Available at: https://www.iese.fraunhofer.de/de/innovation_trends/SmartFarming/cognitive-agriculture.html.

Gabot.de (2011): Projekt: Die größte Aquaponic-Dachfarm der Welt. Available at https://www.gabot.de/ansicht/projekt-die-groesste-aquaponic-dachfarm-der-welt-220400.html.

Global Network of Lighthouse Farms. Netherlands. Available at https://www.lighthousefarmnetwork.com.

Pflanzenforschung.de (2020): Bäume als Schutzwall. Mit Agroforst gegen den Klimawandel und Monotonie. Available at https://www.pflanzenforschung.de/de/pflanzenwissen/journal/baeume-als-schutzwall.

Smee, Jess (2011): Industrial-Sized Rooftop Farm Planned for Berlin. Spiegel. Available at https://www.spiegel.de/international/germany/urban-agriculture-industrial-sized-rooftop-farm-planned-for-berlin-a-800376.html.

Sonin Agency (2019): Lighthouse Projects: Navigating Digital Transformation. Available at https://sonin.agency/lighthouse-projects-digital-transformation-innovation.

Von Geibler, J.; Erdmann, L.; Liedtke, C.; Rohn, H.; Stabe, M.; Berner, S.; Leismann, K.; Schnalzer, K.; Kennedy, K (2014): Exploring the Potential of a German Living Lab Research Infrastructure for the Development of Low Resource Products and Services. Resources 2014, 3, 575-598.

Wageningen University & Research (2017a): Lighthouse Farm Network. Building a global outdoor classroom and laboratory on sustainable foodscapes. Available at: https://www.wur.nl/upload_mm/8/3/f/0803b559-284f-4d8a-a4ad-1eb6b4fc7021_lighthouse%20flyer_online_res.pdf.

Wageningen University & Research (2017b): The lighthouse farm project. Available at https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Farming-Systems-Ecology-Group/Lighthouse-project.htm.

Williams, Dan (2017): Why Lighthouse Projects, Not PowerPoints, Will Unlock Your Transformation Value. Contino.io. Available at: https://www.contino.io/insights/why-lighthouse-projects-not-powerpoints-will-unlock-your-transformation-value.

Annex I – Exemplary Living Lab and Light House Projects Across the EU

Lighthouse Network

Facility type	LH Network
Location	1. Rizoma Agro (Brazil) 2. Palopuro (Finland) 3. Complex Rice Systems (Indonesia) 4. Lands at Dowth (Ireland) 5. GRAND Farm (Austria) 6. Saimniecíbas Kopskats (Latvia) 7. The Atsbi catchment (Ethiopia) 8. La Junquera (Spain) 9. Organopónico Vivero Alamar (Cuba) 10. B.V. ERF (Netherlands) 11. Cauca (Colombia)- mix
Name of facility	Lighthouse Farm Network
Contact name	*https://www.lighthousefarmnetwork.com/lighthouse-farms* *Annemiek Pas Schrijver - Network Coordinator*
Communities involved	In order to have an impact on global agriculture, the Light House projects involve researchers and students in engaging with local communities of actors "to identify and understand barriers to transformation, and either chart a path to removing these, or iteratively redesign the Light Houses to be compatible with local decision making" (Wageningen University & Research 2017a) Each LightHouse farm has collaborations which comes in many forms. Eg. Latvian dairy/caviar/power-station farm is so complex that the Pilvere family employs a hundred experts, from vets to fish farmers to fulltime technicians in the anaerobic digestion plant, to ensure that they have all the expertise needed. (Lighthouse farms ready to meet the challenges of 2050).
Land Use	1. Rizoma Agro (Brazil) – *farmland* 2. Palopuro (Finland) - *farmland* 3. Complex Rice Systems (Indonesia)*farmland* 4. Lands at Dowth (Ireland) - *farmland* 5. GRAND Farm (Austria) - *farmland* 6. Saimniecíbas Kopskats (Latvia)- mix 7. The Atsbi catchment (Ethiopia) – *farmland* 8. La Junquera (Spain) – *farmland* *9.* Organopónico Vivero Alamar (Cuba) - *urban* 10. B.V. ERF (Netherlands) – *farmland* 11. Cauca (Colombia)- mix
Purpose / Issues being explored	1. Rizoma Agro (Brazil) - *Regenerative Agroforestry and Silvo-Pastoral Systems* 2. Palopuro (Finland) - *Community, Energy Production & Biogas* 3. Complex Rice Systems (Indonesia) – *combination of combine rice production with the cultivation of fish, azolla and ducks* 4. Lands at Dowth (Ireland) - *Low Carbon Beef* 5. GRAND Farm (Austria) - *Organic Farming & Vermiculture* 6. Saimniecíbas Kopskats (Latvia) - *biogas production and circular economy* 7. The Atsbi catchment (Ethiopia) - *regenerative agricultural practices*

	8. La Junquera (Spain) – *regenerative agriculture practices* 9. Organopónico Vivero Alamar (Cuba) - *organic urban garden* 10. B.V. ERF (Netherlands) - *Strip Cropping Farming* 11. Cauca (Colombia)- *climate-smart agriculture (CSA) options*
Successes / outcomes	The network has three main goals 1. Providing opportunities for engagement and collaboration with farmers, stakeholders, industry and policy makers, 2. Facilitating valuable shared learning between contrasting "Light House systems" and 3. Providing a platform to anchor international collaborations. No KPIs measurement available in the website for LHs activities.
Outreach activities	List type of demonstration and outreach activities undertaken **in brief** e.g. • hosting training courses; • school visits; • social media; • etc.
References	Global Network of Lighthouse Farms. Netherlands. Available at https://www.lighthousefarmnetwork.com. Rogier Schulte (2020) "Lighthouse farms ready to meet the challenges of 2050" https://uploads-ssl.webflow.com/5e43c55576a554b32716b207/5ecfc9280d06dba251fb889a_Farmers%20Journal%20Article%20FINAL.pdf The light house farm project https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Farming-Systems-Ecology-Group/Lighthouse-project.htm

Lighthouse

Facility type	**LH**
Location	Berlin - DE
Name of facility	"Frisch vom Dach"-project
Contact name	*http://www.ecf-farmsystems.com/* *Nicolas Leshke*
Communities involved	The project is led by ECF is a very Small-and-Medium sized Enterprise which operates an aquaponic urban farm. ECF is a food producer serving 2 distinct markets: 1) supermarkets (for the majority of its sales) 2) HoReCa (Hotels, Restaurants, Catering). Given its urban situation (and commercial positioning), it serves exclusively local businesses. In 2016 and 2017, ECF generated respectively some €240,000 and € 750,000 in sales from the farm. It operates with some 10 staff. (Alexis Figeac, CSCP "ECF Farmsystems - A Circular Economy Business Model Case")
Land Use	• Urban ECF was founded in 2012 and started building its prototype aquaponic farm in Berlin in 2014; the farm started producing in 2015. ECF's aquaponic farm brings together in 1 urban location, fish farming (in vats) and plant cultivation (in a greenhouse). So as to optimise yields (i.e. maintaining homogenous cultivation conditions), it concentrates on 1 species in the respective domains: 1) Fish of the tilapia variety 2) Basil (as a potted herb). (Alexis Figeac, CSCP "ECF Farmsystems - A Circular Economy Business Model Case")
Purpose / Issues being explored	• Creating the world's largest aquaponic roof farm on the roof of the Berliner Malzfabrik in order to practice sustainable agriculture and fish breeding all year round (Gabot 2011) • Opening the market for aquaponic
Successes / outcomes	• The first farm is seen as a proof-of-concept, demonstrating that ECF's farm may be operated efficiently. The company has been leveraging this know-how to set up a 2nd stream of revenue, namely the designing, planning and engineering of aquaponic farms for 3rd parties (turnkey delivery: a rooftop aquaponic farm. (>2000m2) at the Anderlecht Abattoir in Brussels) • Employment for 9 persons on full-time in the heart of Berlin. • Supermarket and ECF save on plastic trays due to fast local delivery in cartons (68'000 units tray units avoided, i.e. about 6.8 tonnes of plastic p.a.); this furthermore translates into a €10'000 financial saving. • Ecological symbiosis of aquaponic operation avoids hazardous runoffs and improves the wellbeing of locals. • Low CO_2 footprint of food deliveries (displacement of high CO_2 deliveries from afar). (Alexis Figeac, CSCP "ECF Farmsystems - A Circular Economy Business Model Case")
Outreach activities	Not reported
References	Gabot.de (2011): Projekt: Die größte Aquaponic-Dachfarm der Welt. Available at https://www.gabot.de/ansicht/projekt-die-groesste-aquaponic-dachfarm-der-welt-220400.html

	Alexis Figeap, CSCP "ECF Farmsystems - A Circular Economy Business Model Case" http://www.r2piproject.eu/wp-content/uploads/2019/06/ECF-Farms-Case-Study_2.pdf

Living Laboratories

Facility type	LL
Location	Löwenberger Land- Berlin- DE
Name of facility	The Ackerbau(m)-Project
Contact name	*https://agroforst-info.de/portfolio-item/ackerbaum/*
Communities involved	The project is led by the University for Sustainable Development in Eberswalde (EUSD). In the design of the project, different stakeholders were considered by Hofman and de Hann (Hofmann P, Hübner-Rosenau D, 2016): • Farmers; • Landowners; • Agroforestry experts; • Nature conservation experts. The implementation is carried out by students from different faculties of the university. The course, offered the first time in the winter semester 2017/2018, represents an innovative form of organising interdisciplinary research. (Hübner-Rosenau and All 2018)
Land Use	• Agroforestry The experimental area comprises approximately 30 hectares (approx. 10 hectares each of agroforestry, zero area, short rotation plantation) of an agriculturally used area (DeFAF 2020).
Purpose / Issues being explored	• In the first run of the module, a high value timber tree system was established, along with the start of additional (research) activities in other areas of the project (e.g. soil, microclimate or public relations). • Experiment innovative form of teaching and learning in which research is carried out on an interdisciplinary basis. (Hübner-Rosenau and All 2018)
Successes / outcomes	• Gain findings to show how a complex agroforestry system can be structured to counteract soil compaction, evaporation, impoverishment, loss and sealing. In the first year, the project elaborated long-term data acquisition to evaluate the project impact but no results were found in English. • Acquisition of technical competences (e.g. agroforestry, landscape management, sustainable development) as well as foresight and management skills. • Very positive feedbacks – especially on the synergy effects of the project - from students and stakeholders. (Hübner-Rosenau and All 2018)
Outreach activities	• Stakeholders interviews • Students – experts working groups • Public planting days • Videos of planting days
References	Hofmann P, Hübner-Rosenau D (2016) Agroforst-Modellprojekt im Löwenberger Land. Eine Konzeption im Spannungsfeld zwischen wissenschaftlicher Aussagekraft, landwirtschaftlicher Praktikabilität

	und komplexer Multifunktionalität. Bachelorarbeit Hochschule für nachhaltige Entwicklung Eberswalde Deutscher Fachverband für Agroforstwirtschaft (DeFAF) e.V. (2020): ACKERBAUM – Das Agroforst Forschungs- und Modellprojekt im Löwenberger Land von der Hochschule für nachhaltige Entwicklung in Eberswalde. Available at https://agroforst-info.de/portfolio-item/ackerbaum/. Hübner-Rosenau and All (2018) Education on agroforesty in the context of sustainbale Development' in Proceedings of the 4th European Agroforestry Conference Agroforestry as Sustainable Land Use

Facility type	LL
Location	The project involves 12 pilot regions in North West Europe over 5 countries (FR, NL, UK, BE and LUX). Solutions are developed in a region-oriented manner, tested and demonstrated across 315 farms.
Name of facility	FABulous Farmers employ Functional AgroBiodiversity (FAB) as a nature-based solution to reduce use of natural and material resources, delivering benefits for farmers, society and the environment in NEW (FABulous Farmers)
Contact name	*https://fabulousfarmers.maesmediatest.be/en*
Communities involved	The project, led by Agro-environmental management centre, includes 12 partners and a network with: • an inner partner circle of farm advisory groups, NGO's, research centres and university researchers • a circle of sub-partners from industry, policy and NGO's • a further circle of 'first adopters', linked into the wider network of growers in the farming industry
Land Use	• Farmland
Purpose / Issues being explored	The project aims to 1. Collect, deepen and share knowledge on FAB; 2. Widen uptake of FAB by farmers through demonstration; 3. Embed FAB in the local society. Functional agrobiodiversity interventions include: reduced tillage; mixed crops/rotation; cover crops; organic matter input; modify manure quality; agroforestry; hedgerow management; field margin management; reduction in the use of plant protection products; semi-natural landscape elements (provide habitat).
Successes / outcomes	• 10 FAB solutions are evaluated for ecological performance and economic profitability, with the aim of reducing the dependence on external inputs by an average of 30%; • The project partners have identified user-friendly tools and methods to measure the environmental and socio-economic performance of FAB solutions with a focus on: ➢ the environmental effects and their measurement (soil, water & ecology) ➢ the farmer costs and benefits (based on farmers needs in the pilot regions) ➢ the social costs and benefits
Outreach activities	The project engages with communities and tests citizen science tools and networks to bring society and farming. Among the activities: • citizen science groups

	• Networking session • Social Media communication • FAB expert contact and advice
References	https://fabulousfarmers.maesmediatest.be/en https://keep.eu/projects/21385/

ANNEX II – SCOPING PAPER ON SOIL HEALTH AND FOOD

A. Introduction

This scoping paper on aims at supporting the Mission Board on Soil Health and Food in their task to define the constituent parts of the mission area. For the Mission Board, the scoping paper provides:

- An overview on the current **state of play** on Soil Health in EU
- Key **trends** that influence Soil Health and Food.
- An outline of **possible targets with analysis of opportunities and risks**

B. Working definitions

- **What is soil health?**

The term soil health is often used interchangeably with soil quality. Whereas soil quality is fairly narrowly defined as, "the soil's fitness to support crop growth without becoming degraded or otherwise harming the environment" (Acton & Gregorich, 1995), soil health is broader. Bünemann *et al.* (2018) argues "that the term soil health encompasses the living and dynamic nature of soil, and that this differentiates it from soil quality". These authors therefore "adopt the view that (....) soil quality focuses more on the soil's capacity to meet defined human needs such as the growth of a particular crop, whilst soil health focuses more on the soil's continued capacity to sustain plant growth and maintain its functions." We propose that 'healthy soils' across ecosystems for food, nature and climate are a desirable goal.

- **Which are the soil functions?**

Soil health is important for delivering soil functions. The 2006 proposal of the European Commission for a Soil Framework Directive introduced seven soil functions (food & biomass production, storing, filtering a& transformation, habitat and gene pool, physical and cultural environment for mankind, source of raw material, carbon pool, geological and archeological archive. Another useful framework is that of natural capital and ecosystem services (Dominati *et al.*, 2010). These various frameworks were synthesised by Keesstra *et al.* (2016), in the context of delivering the sustainable development goals (SDG's) and Figure 1, modified from Keesstra *et al.* (2016), provides an important overarching conceptual framework for the delivery of services and SDG's without degrading the soils natural capital.

- **Which are the soil threats?**

'Recognising the importance of soil degradation the European Commission (EC-231, 2006) identified eight main threats to soil functions (Figure 1): erosion, local and diffuse contamination, loss of organic matter, loss of biodiversity, compaction and other physical soil deterioration, salinisation, floods and landslides, and sealing. 'In some estimates, erosion, organic matter decline, salinization, landslides and soil contamination alone might cost the EU up to €38 billion annually (EC-231, 2006) and the majority of these costs are borne by society. Climatic factors and human actions both threaten soil functioning and natural capital. These threats should not be regarded as distinct, but as interlinked in the sense that threats to soil from human activity can contribute to climate change, and, in turn, climate change causes or intensifies threats to soil' (Robinson *et al.*, 2018).

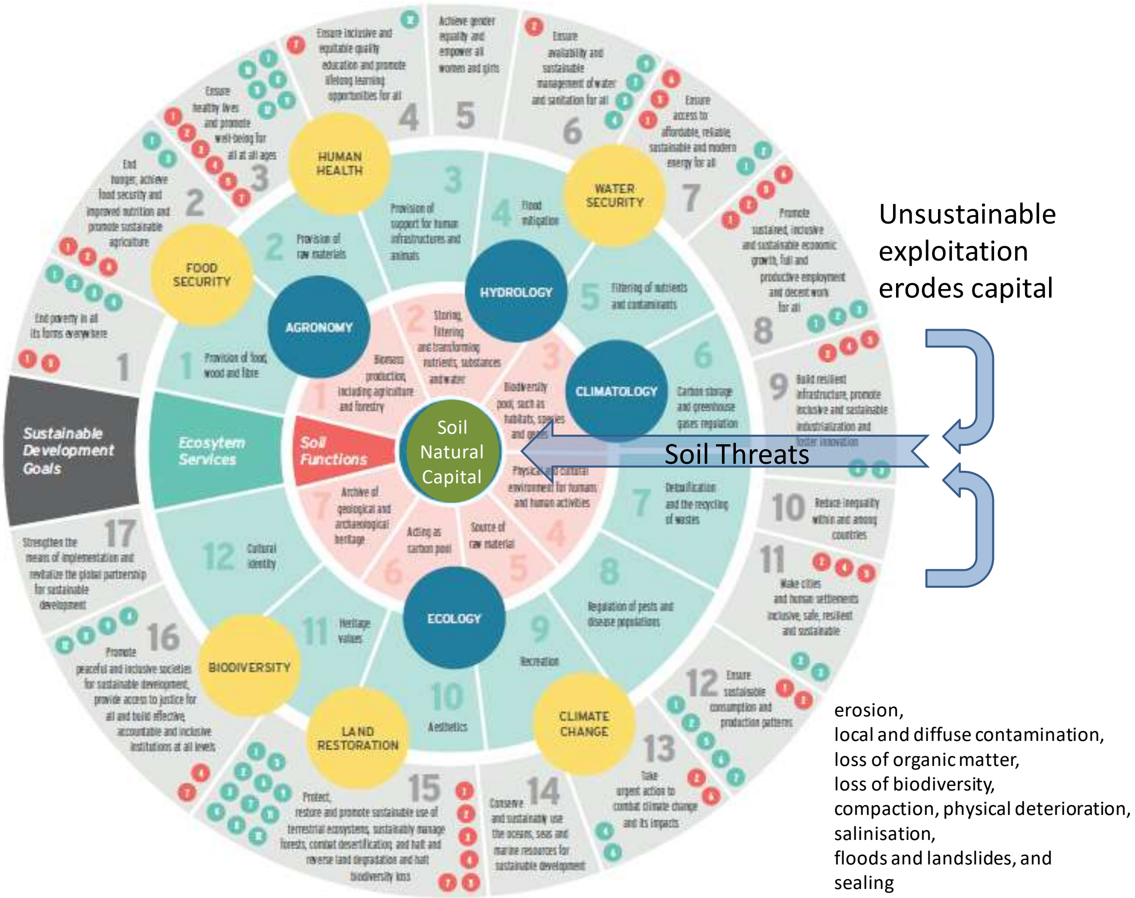

Figure 1. The UN Sustainable Development Goals in relation to soil natural capital, functions and ecosystem services. Modified from (Keesstra *et al.*, 2016, Robinson *et al.*, 2018)

- **Global soil change**

'Soils are dynamic and change over time. 'Pedology, over the last 100 years, has focused extensively on the gradual change resulting in soil formation, encapsulated in Jenny's five factors of soil formation, CL, O, R, P, T (CLimate, Organisms, Relief, Parent-material, all as a function of Time). However, there is growing recognition of the strong influence of anthropogenic soil change (Richter *et al.*, 2011). Estimates for the next 50 years indicate that mankind is moving to a global density of 1 person for each 0.01 km^2 of reasonably biologically productive land (Certini & Scalenghe, 2006). This increase in population pressure means that we must continue to extract more from our soils to support the growing demand' (Robinson *et al.*, 2012).

Drivers of Soil Change: 'Tillage, , drainage, agricultural traffic, irrigation, drainage, over fertilisation and pollution e.g. (pesticide application and industrial emissions) are perhaps the main drivers of anthropogenic soil change and are mostly related to food production. Of the Earth's terrestrial land surface, c.134 million km^2 (Mkm^2), arable agriculture was estimated to cover 15 Mkm^2, and managed grazing 28 Mkm^2, whilst the amount of land irrigated was estimated to be 2.7 Mkm^2 in 2000. This means that c.38% of the Earth's ice-free land surface is currently used for agriculture, with this land replacing forests, savannahs and grasslands.

Indirect Drivers of Soil Change 'Mankind is transforming the Earth system through climate and land-use change as well as the movement of invasive species. Soils, forming the thin interface at the Earth's surface, interact with the atmosphere, hydrosphere, lithosphere and biosphere, so that as they alter, soils are often also altered.' Global emissions of N_2O, NH_3 and SO_2 are estimated to have increased by more than a factor of 3 since the pre-industrial era, largely due to the use of fossil fuels and agricultural production. Alteration of rainfall patterns are chiefly associated with climate change due to natural perturbation and human activity. Moreover, declines in soil moisture across Europe have been linked to the increased intensity of heatwaves in the last few decades (Seneviratne *et al.*, 2006). The largest pressure on the biosphere has been land use change, the planting and removal of trees, and the transition to monocultures in agriculture and plantation forestry.' Currently the EU is 28% arable (double the global average), 16% permanent grass, 4% permanent crops and 36% forest (EC, 2018). Biosphere change indirectly affects soil biota and the processes that they drive, by altering plant community composition, nutrient cycling, carbon allocation patterns, or the quantity and quality of plant-derived organic materials. The accumulation of metals presents one of the more serious long-term threats to soil sustainability worldwide as they are not broken down. Many of these processes, and linkages between above and below ground, are not well understood' (Robinson *et al.*, 2012)

- **International goals and strategies**

As a basis for discussion of Goals and Targets for soil health and food we refer to the work of the United Nations as the overarching framework, which includes **the sustainable development goals (SDG's)** illustrated in the figure 1. As Tóth *et al.* (2018) points out, in agreement with Keesstra *et al.* (2016) 'SDGs 2, 3, 6, 11, 13, 14, and 15 all have targets which commend direct consideration of soil resources.' However, only four SDGs explicitly mention soil, and only 15.3 has actually adopted a soil indicator (in the form of SOC):

- **SDG 2.4** By 2030 ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality
- **SDG 3.9** By 2030 substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination
- **SDG 12.4** By 2030, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
- **SDG 15.3** By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world. Under SDG sub Target 15.3.1 indicator, SOC is assessed as one of three sub indicators (land cover [metric: land-cover change]; land productivity [metric: net primary productivity]; and carbon stocks above and below ground [metric: SOC]) of indicator 15.3.1 ("Proportion of land that is degraded over total land area"), in accordance with the UNCCD's LDN concept.

The international initiative "4 per 1000", launched by France in 2015 at the COP 21, federates all voluntary stakeholders of the public and private sectors under the framework of the Lima-Paris Action Plan (LPAP). The aim is to demonstrate that agriculture, and in particular agricultural soils can play a crucial role where food security and climate change are concerned (https://www.4p1000.org/). Although not a normative target for each country, an annual growth rate of 0.4% in the soil carbon stocks in the first 30-40 cm of soil would significantly reduce the CO2 concentration in the atmosphere related to human activities

The soils community has organised through the United Nations Food and Agriculture (FAO) a directorate to tackle challenges in soil science including SDG's. Work is undertaken through the **Global Soil Partnership** and the **UN Intergovernmental Technical Panel on Soils (ITPS)**. Important contributions include:

- The revised World Soil Charter, see: (Montanarella, 2015), which sets out principles and guidelines for actions by individuals, groups, governments and international organizations. 'The overarching goal for all parties is to ensure that soils are managed sustainably and that degraded soils are rehabilitated or restored.'
- The Status of the World's Soil Resources report (FAO-ITPS, 2015), which identified four priority actions:

1. Sustainable soil management to increase the supply of healthy food specifically in those regions where people are most vulnerable.
2. The global stores of soil organic matter (e.g. SOC and soil organisms) should be stabilized or increased. Each nation should identify locally appropriate SOC-improving management practices and facilitate their implementation. They should also work towards a national-level goal of achieving a stable or positive net SOC balance.
3. Action should be taken to stabilize or reduce global nitrogen (N) and phosphorous (P) fertilizer use while simultaneously increasing fertilizer use in regions of nutrient deficiency. Increasing the efficiency of N and P use by plants is a key requirement to achieve this goal.
4. The regional assessments in this report frequently base their evaluations on observations made in the 1980s or earlier. We must improve our knowledge about the current state and trends in the condition of soil, with initial emphasis on improving observation systems to monitor our progress in achieving the three priorities outlined above.

- **European initiatives**

At the European level, the Thematic Strategy for Soil Protection (adopted, Sept 2006) consists of:

- A Communication from the Commission (COM(2006) 231) (EC-231, 2006), which explains why further action is needed to ensure a high level of soil protection, sets the overall objective of the Strategy and explains what kind of measures must be taken. It establishes a ten-year work program for the European Commission.
- The proposal for a framework Directive (COM(2006) 232) (EC-232, 2006), which sets out common principles for protecting soils across the EU while leaving it to the EU Member States to decide how best to protect soil and use it in a sustainable way on their own territory.
- An Impact Assessment (SEC (2006) 1165 (EC-1165, 2006) and (EC-620, 2006), which contains an analysis of the economic, social and environmental impacts of the

different options considered in the preparatory phase of the strategy and of the measures finally retained by the Commission.

Although it was rejected by the Council in December 2007, the Commission's proposal for a Directive sets out an important framework that identifies the challenges and major threats to soils across the EU, calling for Member States to identify areas at risk of erosion, organic matter decline, compaction, salinisation, and landslides, adopt risk reduction targets and establish programmes of measures to reach them, and establish a National Remediation Strategy.'

'Option 3 of the proposed Directive, which advocates the creation of EU legislation for the different soil threats, setting all objectives, targets and means at EU level, was rejected on the grounds that:

- It is very difficult to establish general EU-wide soil quality standards and measures to address soil threats.
- Historically, some national, regional and local authorities have dealt with soil, generating significant knowledge on where and how to address soil protection in their particular areas. It seems therefore appropriate that full use is made of this experience.
- Detailed and harmonised data and information at Community level on soil degradation is limited.'

However, the soil thematic strategy continued to operate, but with no legal basis (EC-46, 2012). While this was not undertaken, the work identifies the critical soil threats across the EU, the tackling of which could be considered in a goal based framework. Both the work of the UN and the EU highlight a common set of issues to be addressed to attain healthy soils across land use types.

New and emerging initiatives that will impact soil include, the Green Deal for Europe, with the EU aiming for climate-neutrality by no later than 2050 and implications for biodiversity, zero pollution and land degradation. In addition, there are the proposed new CAP and LULUCF regulations. While the recent auditors report (ECA 33/2018) has highlighted the growing threat of land degradation by desertification, especially in Southern Europe.

A new European Joint Programme "Towards climate-smart sustainable management of agricultural soils" was launched in 2020 under Horizon 2020 Societal Challenge 2 "to construct a sustainable framework for an integrated community of research groups working on related aspects of agricultural soil management". According to the Work Programme 2018-2020, "the activities should look at how management of agricultural soils can reduce degradation of land and soils (in particular soil erosion and loss of organic matter), preserve and increase fertility of soils and how the processes related to organic content and water retaining capacity can support mitigation and adaptation to climate change". The programme is co-financed by the EC and MS/AC.

The EU concern of soil health was projected in the Cross Compliance introduced in 2003 CAP reform in connection to the decoupling of direct payments ((EC) No 1782/2003.) Since that, Cross compliance is an integral part of CAP and its supports. Farmers are expected to comply with i) statutory management requirements (SMR - 8 EU legislative rules) and ii) good agricultural and environmental conditions (GAEC). Particularly GAEC addresses soil health in three of its objectives

- prevent soil erosion by defining minimum soil cover and minimum land management practices

- maintain soil organic matter and soil structure
- maintain permanent grassland

In the proposal on the CAP after 2020 (COM(2018) 392 final) the Commission pays strong attention to soil health under the objective Environment Care. However, goals are not complemented by targets (target levels which should be achieved). The specification of measures and thus the targets is let to MS.

- **How is soil health currently measured?**

Both the ITPS and EU recognise the need for assessment of soil state and change as a basis for decision making. There is no global program currently that does this, which can be achieved through monitoring (Robinson, 2015), though there are efforts to harmonise existing data. The EU has embarked on an EU wide soil assessment of soil state and change under the LUCAS monitoring program since 2009 (Orgiazzi *et al.*, 2018). This provides an important platform, but has some important constraints such as limitation of soil depth (~0-20cm) and habitat types monitored. While this important effort captures change on a ~5 year cycle, there is currently no matching ground based sensor network across the EU to capture soil dynamic responses such as soil moisture and soil temperature which are important for a range of societal issues such as the development and persistence of heat and cold waves, wildfire occurrence as well as crop production.

C. Key trends for soil health and food

Trends and weak signals – an overview

The analysis takes into consideration five out of seven soil functions: there are those that are mainly affected by soil management and are most relevant for societal challenges and contributing to SDGs (Techen & Helming, 2017). The table contains a preliminary assessment of trends impact on the soil functions.

CONSOLIDATED TRENDS		**Biophysical**			**Biophysical & socio-economic**			**Socio-economic**			**Technological**	
		Decreasing agro-biodiversity	Sea level rise and ocean acidification	European Forests: upward trend	Climate change management	Sustainable intensification and agroecology	Urbanised soil	Structural change in agriculture	increased imbalance of access to	Reduction of food waste and loss	Digitalization of the agri-food sector	Machine farming
Soil Function impact	Production of food, fibre & biofuels + timber	x	x	x	x	x	x	x	x		x	
	Water purification & retention			x	x			x	x	x	x	x
	Carbon Sequestration			x	x			x			x	
	Habitat for biodiversity	x	x	x	x	x	x	x			x	
	Recycling of nutrients & Agrochemical				x			x	x	x	x	

WEAK SIGNALS		**Biophysical**	**Biophysical & socio-economic**	**Socio-economic**		**Socio-economic & technological**	
		Controlled & reduced antimicrobial use in food production	Regenerative agriculture	Diversifying nutrition patterns	Emerging new food chain risks	circularity of production’	Towards pesticides-free agriculture
Soil Function impact	Production of food, fibre & biofuels + timber	x		x	x	x	x
	Water purification & retention		x	x		x	x
	Carbon Sequestration		x	x		x	
	Habitat for biodiversity	x	x	x	x	x	x
	Recycling of nutrients & Agrochemical					x	

Consolidated trends

- **Decreasing agrobiodiversity**

We consider here three dimensions of agrobiodiversity: a) below ground, b) above ground and c) food-related. **Soil agrobiodiversity was consistently observed to decline with intensification of agriculture** as a consequence of periodic soil disturbance (especially tilling) that negatively affects, in particular, larger and longer living soil animals (earthworms, collembola) (Tsiafouli et al., 2014). Also plant protection products, especially fungicides and insecticides have been proved to reduce abundance and diversity of the earths fauna (FAO and ITPS, 2017), fungi and bacteria. Intensification, with the development of "industrial" agriculture via specialisation and simplification, led, by construction, to a reduction of biodiversity at the landscape and at the field level. The loss of tree lines, hedges, uncultivated patches, together with the use of insecticides has had an impact also on non-noxious or useful arthropods, especially pollinators (Vanbergen and IPI, 2013).

The diversity of species used for human nourishment has been declining fast with the onset of intensive farming systems that are prevalent today in all developed countries and spreading fast to DVC; of the almost 400 thousand plant species known to science, between 5 and 6 thousand have been used as human food (Royal Botanic Gardens Kew, 2016) but just three of them, rice, wheat and maize account for more than half of plant-derived calories in human diets; twelve crops and five (out of forty domesticated) animal species provide 75% of the world's food (FAO, 2015).

Not only some plants are disappearing from the market, but the gene pool of those that survive is shrinking; industrial breeding and intensive agriculture orientate cultivation (and market) to fewer and fewer cultivars with characteristics that are desirable from the commercial point of view (productivity, appearance, shelf life, uniformity, convenience) irrespective of the intrinsic nutritional value. Ongoing mergers among the big industrial seed industries determine a further focus on "blockbuster" genetic lines and crops, restricting the gene pool of breeding plans (IPES-Food, 2017) and leaving most nutritionally important species at the margins of breeding work.

Soil Health and Food implications – indicators: Agrobiodiversity index (Bioversity International); D1c. Status of pollinating insects (UK); Soil biodiversity index (Cameron et al, 2014, PNAS 111,

Despite the limited understanding of the complex relationships among the components of soil ecosystems, it can be assumed that a simplification of the underground communities leads to loss of functionality and resilience. Pollinators, bees in the first line, are key to reproduction of 75% of our food crops (Klein A-M et al, 2006) and nearly 90% of wild flowering plants. A decline in abundance and viability of pollinator populations jeopardises essential food chains. In some regions of China farmers pollinate fruit tree flowers manually due to the extermination of pollinators.

Agrobiodiversity is also essential among species (plants and animals) raised for food. Diverse diets are fundamental for healthy and balanced nutrition. Currently one third of the world population suffers from micronutrient deficiencies, often simultaneously with excess calorie uptake, leading to obesity and, consequently, to a series of diet-related NCDs. Starchy food (including potatoes and cassava) are rich in calories but poor of minerals and vitamins. Traditional agricultural systems could achieve a balanced nutrient uptake by complementing energy food with a variety of nutrient rich plants (legumes, vegetables, fruit, nuts and whole grains).

Seed vaults and gene banks are increasingly advocated and set up to diminish risks of permanent losses, but ensuring diversity in the fields is essential and this can only be driven by demand.

Impact on soil function Failure to safeguard soil biodiversity leads to an impairment of essential soil functions: N fixation, nitrification and denitrification, cellulose and other organic materials decomposition, methane oxidation, nutrient transfer by mycorrhizae.)

- **Sea level rise and Ocean acidification**

The consequences of mounting CO_2 concentration in the atmosphere and of increasing temperatures are felt also at sea. a) higher water temperatures intensify the strength of extreme weather events (e.g.tropical cyclones), including floods provoked by exceptional rainfalls; b) lower water pH due to the absorption of CO_2 by water harming coral reefs and shell molluscs; c) increasing sea level due to water thermal expansion and to ice cover melting. Whereas the former (a) increases soil erosion and land degradation without an *a-priori* identification of the most susceptible sites and (b) acidification has no direct impact on soils, the rising sea level (c) poses the most serious threats to the low-lying coastal zones of the world, home to nearly 10% of the 2010 global population. Sea level rise was on average 1.4 mm yr^{-1} from 1902 to 2015 (i.e. 16 cm in little more than a century) but 3.6 mm yr^{-1} in the last decade, showing a remarkable acceleration. Coastal ecosystems are affected by salinity intrusion and sea level rise with already visible impacts; vegetated coastal ecosystems (especially wetlands) are shrinking, exposing upstream areas to erosion and salinization, the latter phenomenon due both to sea level rise and to inland penetration of the saline wedge. *Sea level is expected to further rise 0.4-1.0 m by the end of this century.* In many coastal areas the phenomenon is exacerbated by subsidence, the lowering of land level due to water, gas or oil extraction.

Soil Health and Food implications Floods may have a beneficial effect (e.g. the Nile river floods of antiquity) until the benefits deriving from deposition of nutrient rich silt is more than offset by erosion. Indeed, where the slope of terrain does not allow any form of deposition, only erosion remains as a tangible effect of major precipitation events. *In Europe more frequent intense precipitation will exacerbate an already alarming level of soil loss due to water erosion estimated at 2.40 t $ha^{-1}yr^{-1}$, or 970 M tons yr^{-1} for EU28.*

Saline water intrusion on coastal areas is often worsened by water pumping of groundwater for civil and farming needs. This diminishes the pressure exerted by the freshwater table on saltwater intrusion. Where agricultural withdrawals include brackish waters in the boundary layers, salt accumulates on fields due to evaporation.

Impact on soil function – indicator: Soil Electrical Conductivity (EC; adopted by GSP for the Global Soil Salinity Map - GSSMap) High salt concentrations result in high osmotic potential of the soil solution, so plants have to use more energy to absorb water. Under extreme saline conditions, plants may be unable to absorb water and will wilt, even when the surrounding soil is saturated.

- **European Forests: upward trend in surface and stock**

Global forest area fell by 3% from 1990 (4128 M ha) to 2015 (3999 M ha) according to FAO (2015), although the rate of deforestation slowed down between 2010 and 2015 with respect to the previous two decades. European forests, on the contrary, have expanded since 1990, from 994 Mha to 1015 Mha. At present Europe has the largest share (25%) of the World's forests and they represent a net carbon sink, absorbing almost 9% of the continent's greenhouse gas emissions. By far the largest forest area is represented by the Russian Federation (815 Mha); at a distance followed by Sweden (28.1 Mha), Finland (22.2), Spain (18.4) and France (17,0). Most of the increase in surface is due to the expansion of forests in Western Europe.

The main (renewable) raw material provided by forests is of course wood, in itself of a rather low market value, but with a high value added in the industrial processing for the production of pulp and paper (paper decreasing, cardboard increasing), sawnwood and reconstituted panels (rapidly increasing). There is a growing interest in wood as a building material, as it stores carbon for a long time and can be used as a substitute for other (energy intensive) building materials (concrete, steel). Innovation in building technologies based on wood is booming (https://www.bbc.com/future/article/20190717-climate-change-wooden-architecture-concrete-global-warming).

In the last decade big pulp and paper companies have diversified production to make best use of byproducts and have turned into integrated biofactories (textiles, bioplastics) and biorefineries in the context of the Bioeconomy strategies that the EU and most European MS have developed.

A growing demand for wood as a renewable raw material, however, is creating conflicts with the objectives of carbon storage in order to mitigate climate change. The main challenge for the future of forests is then to reconcile all the different expectations, all of them desirable form some point of view

At the moment most forests in Europe (with the exception of Sweden and Finland and a few other countries) are underutilised: less wood is harvested than the annual increment. It may seem, therefore, that there is a significant margin to increase production (withdrawing the "interest") with no damage to forests (protecting the "principal"). However, this argument should be scrutinised at the very local level, as some areas are not harvested to their productive potential because the cost of operations would surpass the value of wood (e.g. steep slopes, roadless areas, …). A more intensive extraction of biomass, as has been sometimes suggested, to include branches and stumps runs the risk of reducing fertility. Indeed, a higher harvesting rate is contrary to the increasingly important expectation about forests to act as carbon sinks, stocking carbon in trees and soil as well.

Soil Health and Food implications A possible increase of biomass extraction form forests, due to the growing demand for renewable raw-materials and energy implies three main risks: a) extraction in excess of the capacity of the environment to maintain soil functionality, biodiversity, fertility in order to ensure the long term achievement of sustained productivity and provision of essential environmental services; b) soil compaction due to increased mechanisation of operations; c) increasing carbon emissions due to operations aimed at facilitating reforestation (e.g. scarification). Possible indicators are i) Periodical Carbon balances performed under the Kyoto Protocol ii) Statistics on forest/plantation surfaces for the periodical FAO Forest Resource Assessments

Impact on Soil Function Forest soils are very diverse across Europe and little known except for descriptive characteristics (soil layers, entomofauna, fungi). The relationships between the different physical and biological elements, as well as the effect of perturbations, remain largely unknown. The possible growing impacts of forestry operations on soil functions is mainly a matter of conjecture. A precautionary principle should be applied, allowing new or more intense practices once their compatibility of soil functions is established.

- **Climate change management**

The majority of food production systems depend on regional climate conditions and will be affected by changes in global temperature, water scarcity, distribution of crop and livestock diseases, as well as by the occurrence of extreme weather events. Climate change increases yield losses caused by natural disasters as e.g. cyclones, droughts or floods. To protect against such large-scale events, insurances and infrastructural installations, as well as the selection of arable crops have to adapt to these new framework conditions. In addition, tropical zones, where poor and agricultural dependent people live, will be most affected. Climate-smart agriculture (CSA) proposes one way of addressing these challenges by a sustainable improvement of productivity, both mitigating and adapting to climate change.

Soil Health and Food implications The changing climate obliges humanity to find new solutions for guaranteeing high levels of food supply, to make society more resilient, and to stabilise climate conditions now and for future generations. Climate disasters lead to increased conflict and make people flee from unusable soils. By exhausting the still remaining well-functioning soils, the climate crisis might multiply the negative effects of human activities on soil.

Impact on soil function The climate crisis, and notably extreme weather events such as droughts, heavy rains and floods, directly lowers soil functions, and leads to faster soil erosion and decreased soil biodiversity.

- **Increasing importance of sustainable intensification and agroecology**

Agricultural intensification, combined with the growing homogenization of the global food system, has led to a range of negative impacts, including biodiversity loss, environmental degradation and decreased dietary and nutritional diversity. The concept of **"sustainable" intensification** invokes new technological developments that may meet increasing demands for food and feed without any further stress on environmental resources. The key is higher efficiency in the use of resources, e.g. *by precision agricultural practices (Van Woensel et al., 2016), exploitation of earth observation data, recourse to renewable energy sources, use of genetically improved cultivars that resist diseases, droughts, heat*. The reasoning behind the concept of sustainable intensification is that if the world is facing a growing demand for food and feed, due to increasing consumption of meat and other animal-source food) as well as for biomass for energy and biobased products to replace fossil fuel based products and to implement bioeconomy strategies (Helming et all., 2018). At the same time no more land should be converted from forests to pastures to crops, the only solution is to make better use of what we have by increasing efficiency thanks to technological innovation, and moving where possible to soilless food production.

Despite a broad support from mainstream agricultural subjects, including FAO, that consider sustainable intensification "both possible and necessary", this concept is criticised by those who advocate a more radical systematic change from the current "industrial" agriculture model, mostly based on external input application (however improved in efficiency) to an agroecological model in which external inputs are minimised and replaced by synergistic (or antagonistic) ecological relationships between components of the agroecosystems; this approach is sometimes dubbed as "**ecological intensification"** (Tittonell P, 2014). Supporters of "ecological intensification" consider the term "sustainable" associated to intensification to be an attempt to "greenwash" the current mainstream agricultural system.

Sustainable intensification has a high technological component whereas ecological intensification is based mainly on socio-economic factors (farmers) and biological relationships (ecosystem elements) At territorial levels, sustainable intensification is mostly advocated in developed countries, although the return on investments in technology would be higher where the productivity gap is still high and an adoption of smart methods could avoid the negative externalities produced in advanced systems.

Regarding the time horizon, both "sustainable" and "ecological" intensification require at least a decade to become firmly established. Especially the transition to agroecology requires some years to reconstitute the complexity of agroecosystems.

Soil Health and Food implications It is expected that the widespread application of **precision agriculture techniques** will improve a broad range of soil quality aspects; the overall amount of fertilisers and plant protection products could be significantly reduced; driverless GPS-guided machinery, drones and robots may lead to lighter equipment and timely execution reducing compaction; in principle, the application of advanced technology would make the adoption of more complex (and environmentally friendly) cropping systems more feasible, e.g. strip cultivation alternating cereals and nitrogen-fixing plants.

Ecological intensification would probably rely on higher human labour amounts per unit product or surface to cope with more complex agroecosystems (cover crops, catch crops, perennials, agroforestry, integration of livestock) but at the same time a reduction of costs for external inputs (plant protection products, fertilisers).

Impact on soil function A reduced use of synthetic inputs and irrigation water, as well as lighter equipment and timely execution of field operation would reduce pollution (with positive impact on soil biodiversity), erosion and compaction. More significant soil quality improvements are expected from a transition to agroecology (or ecological intensification) as the lack of synthetic inputs would make the maintenance and enhancement of fertility dependent on a rich and healthy underground ecosystem.

- **Urbanised soil**

The major part of a booming global human population has chosen to settle in urban environments. Living constructions and infrastructure have led to accelerated soil sealing, resulting in a loss of green and an increase of grey soil. Organic and inorganic pollutants caused by living communities stress the soil and put considerable health risks on the townsfolk. With urban populations projected to continue increasing, demand for more housing and transport is putting pressure on green spaces. At the same time, cities are increasingly greening spaces to reduce air pollution, improve the quality of living, and reduce the risks of climate change. 53.9 % of the world's population lives in urban areas in 2015, expected to increase to 68% by 2050. Europe's level of urbanization is expected to increase from 73.9 % in 2015 to 83.7% in 2050. (UN 2018)

Soil Health and Food implications Urban areas need buildings and infrastructure for their citizens, which inevitably leads to soil sealing. Soils being urbanized become compacted, lose biodiversity, and over the time accumulate pollutants that negatively affect the citizen's health. Growing food in or on urban buildings (indoor, vertical, rooftop farming, aquaponics, etc.) can be solutions for food shortages and climate risks, but do not address the problems of urbanized and sealed soils. Community gardening in urban spaces in developed countries aims less on food or economic benefits, but more on practicing sustainable activities and social cohesion.

Impact on soil function – indicator: In Europe, no reversal of sealing soil can be observed, although there is political commitment to stop further sealing. (Artmann, 2014)

- **Structural change in agriculture**

Agriculture has been experiencing a drastic structural transformation during the last decades. Many European family farms are closing down, being rented out or sold outside the family. The discontinuity of family farms is expected to lead to changes in the organisation of farm production, and consequently to changes in agricultural landscapes and agrarian development. Large retail stores and discounters have largely replaced the traditional supply structure of small-scale grocery retail. Ironically, rural populations are most exposed to poverty and hunger when they feed worldwide consumers, as power shifts from consumer goods producers to retailers, with the latter controlling the main distribution channels. This gatekeeper function allows retailers to exert their influence on prices, quality, assortment, and production conditions, although they increasingly face the pressure resulting from the emergence of e-commerce in the food-sector.

Soil Health and Food implications The trend away from smaller-scale family farming towards big-scale retailer farming is questioning complex and diverse ethical principles. As agricultural products are easy to compare for the consumer in retail stores, retailers face hard price competition. As a result, agriculture is increasingly regulated by consumption and legal frameworks, which leads to a race-to-bottom of quality standards of products, production systems and soil practice.

Impact on soil function In global production systems of growing transnational retailers, soil is mostly treated as an input for the creation of economic value. Therefore, soil is considered as a replaceable resource, which fulfils its function when it delivers profit. Complex soil functions, e.g. as a biosphere or a living space for rural communities, are pushed to the background in the face of powerful stakeholders as consumers and shareholders.

Increased imbalance of access to common goods The unprecedented rise of the global population in a finite world has dramatically changed the outer earth layer. Disintegrity on various aspects of governance, as the disregard of ecological conditions produce grave direct effects on human rights (to water or food) and, indirectly, also on human security. Facing the destruction of ecosystem services, essential questions about basic human rights on ecosystem services and soil pop up, e.g. "who owns the soil?", "who is responsible to manage the soils?", and "is public regulation of soils justified—and to what extent?" The financial crisis 2007/2008 has reinvigorated landgrabbing activity. On the other hand, volatile commodity prices have led to increasing food riots, where citizens demonstrate for their right for food and provision. The concept of ecosystem services illustrates the variety of beneficiaries of multifaceted soil ecosystem services Helming et al., (2018). Good land policy provides a diversity of land uses with plural property relations.

Soil Health and Food implications The definition of which is a human right and which are property rights on soil allow the allocation of responsibility for land use at individual or common level. The clearer these rights are defined, the agiler policies can realize common will, and the better free riding in the global community can be avoided, which would lead to a more efficient use of soil for food and health.

Impact on soil function The multifunctionality of soils and an attribute-based property rights perspective implies special obligations towards the common good. Soil and Ecosystem services as common goods are very vulnerable to free riding, where an individual accepts loss of common benefit as long as the individual wins relatively. Therefore, individuals free ride, accepting loss of soil functions as long as personal benefits are expected. The responsibility for common goods is usually externalized from individual to collective level, expressed in politics and legal frameworks. But the effectiveness of protection or even improvement of soil functions is rather determined by the based ethical framework for politics and/or for personal behaviour.

- **Reduction of Food Waste and Losses**

Recent years have seen an increase in public awareness about food waste in the developed world. Food is lost along the entire food value chain. Some countries (e.g. France) have established laws prohibiting retailers from throwing away unsold, edible food, and requiring them to donate it appropriately. As 23.9 percent of the world's population suffer from moderate or severe food insecurity, and 10.8 percent are malnourished, the amount of food waste in the industrialized world signals inefficiency of the global food system. The rising world population makes it necessary to reduce food waste to feed the rising number of people. The global economic cost of food waste is $ 750 billion and primarily damages consumers and farmers. Local initiatives such as food sharing, which collect surplus food, are on the rise.

Soil Health and Food implications Food waste and losses are an expression of inefficient food supply chains. Wasted and lost food must be produced, which means that soil is wasted for the delivery of food waste

Impact on soil function Food waste does not directly impact on soil functions. Nevertheless, in a world with decreasing space for a growing population, soil is wasted when it is used for the production of food destined to be discarded. Therefore, food waste is lowering the global soil function.

- **Digitalization of the agri-food sector**

Innovative information and communication technologies (ICTs) applied to agriculture, food value chains, and nutrition help addressing environmental, economic, and social challenges in the agri-food sector by creating an opportunity to network, trade, and share "know-hows" among involved stakeholders. Precision agriculture solutions including the site- and plant-specific approaches of agricultural soil management and enabled by increased implementation of sensor technologies aboveground (drones and GIS approaches) and belowground, blockchain, the Internet of things (IoT), big data analysis, and artificial intelligence (AI) technologies allows sustainable agricultural production as well as more transparent and straight-forward marketing processes (Techen & Helming, 2017). The blockchain-technology and smart contracts support the responsible use and implementation of data, which provide optimization of farming resources. Moreover, smart contracts (*e.g.* in agricultural insurances) could be also used to minimize farming risks induced by extreme weather events using the blockchain-enabled weather control process.

Soil Health and Food implications Implications are manifold: higher yields at reduced agricultural inputs to soils based on the site- or plant-specific requirements, plant disease detection, in-field traffic management, crop monitoring, weed control, diminished re-distribution of excessive agricultural inputs into the aquatic bodies, prevention and management of soil erosion, less manpower and shorter working time, capacity for longer operational hours, fair trade, reduced soil top- and subsoil compaction, productivity estimation, climate change analytics, smaller fields and optimized inter-row cropping and rotation, land registration, reduced mental stress if cyber security is granted. Measurement of the provision of soil related ecosystem services possible as a basis for ecosystem services-oriented subsidy schemes.

Impact on soil function Optimized soil management practices based on the crop and soil monitoring, agricultural robots, and predictive analytics allow sustainable farming intensification with consideration of soil heterogeneity. From a more holistic perspective, digitalization depends on metals and rare-earth elements, of which exploitation has negative impacts on soil (mostly in developing countries). Increasingly short life cycles of digital devices have led to the fastest growing waste stream on earth. Only one fifth of the e-waste is formally recycled, the mayor part is dumped to landfill, releasing toxic heavy metals (e.g. lead, arsenic and cadmium) to the soil. Therefore, digitalization is a double edged sword, potentially decreasing pollution where it is used, but increasingly polluting soils in both countries of extraction and dumping.

- **Machine Farming**

Food processing has become a key factor in the transformation of food systems, leading to the standardization of agricultural output and, in many cases, the localization of primary production and the consolidation of farmland. Many smallholder farmers have become landless agricultural workers, or have migrated to towns and cities in search of employment, accelerating urbanization.

In this context of standardization, two main trends have emerged: a) precision farming to serve the ultimate goal of applied technology in agriculture i.e. to proliferate yields, reduce harvest times, and reduce costs and environmental impact. In the long term, it is foreseeable that the farms of tomorrow may no longer need people to grow crops at all; b) automated indoor farming. There are a number of reasons to move farming indoors. In areas where water resources are lacking, growing vegetables can be challenging. In such cases, factory farming, which is mostly indoors, may be viable and scalable. In the long run agriculture could become fully automatized, first in areas with a lack of human workers and extreme conditions and then around the globe. This could have disruptive impacts in areas like food culture, sustainability, social fabric and employment.

Soil Health and Food implications This type of agriculture relies on the latest ICT available – GPS, satellite imagery, control systems, sensors, robots, variable rate technology, telematics, software, etc. – to improve crops in every step of the growth cycle: soil preparation, seeding, and harvesting. Artificial intelligence supports the management of species, field conditions, crop and livestock, and is also a big help in food sorting, quality control and safety compliance, consumer engagement, production, packaging and maintenance. Additionally, the indoor farming might be a good option in areas with high radioactivity – such as those experiencing the aftermath of nuclear disasters – where there are fears that traditionally grown produce could contain radioactive fallout. In food industries, neural networks are already used to improve process dynamics with various raw materials and different processing conditions. A new iceberg lettuce harvesting system is able to harvest with a 91 percent accuracy and error rate for false positives of 1.5 percent.

Impact on soil function Precision farming leads to a site specific management and therefore reduces certain negative impacts on soil, e.g. demand-based fertilisation. In addition, smaller (unmanned) farming machinery leads to less soil compaction.

Weak signals

- **Controlled and reduced antimicrobial use in food production**

The growing drug resistance induced by continued use of antibiotics in agriculture may affect human health worldwide. In the agri-food sector, antimicrobials are mostly used for livestock, while the contamination of soils occurs via manure, leaching, and production. Soils are "banks" for drug discovery that can assist minimizing 'superbugs' resistant to medical treatment by finding new medicine. Though, the antimicrobial use needs to be controlled in the agri-food sector to preserve the biodiversity and reduce the current impacts on human health. Some targets were set for the food animal production, e.g. by Denmark: < 50 mg of antibiotics should be used per year per kg of livestock was set a starting point for such a target (AMR Review, 2015). However, no specific limits are available for concentrations in soils.

Soil Health and Food implications Biodiversity loss, plant and livestock resistance to diseases that may lead to human health issues, human pathogens, locations with high concentrations of antimicrobials leading to water contamination.

Impact on soil function Antibiotic uptake by plants from agricultural lands with manure applications affects food quality. The presence of antimicrobials driven by the agri-food sector affects soil biodiversity by increasing transferred resistance genes in the rhizosphere.

- **Regenerative agriculture**

Regenerative agriculture can be considered as one of the variants of agroecology or permaculture, that is agriculture that limits or avoids tilling and replaces external chemical inputs (fertilisers and plant protection products) with the relationships established by different components of the agroecosystems: "design", that is a deliberate choice of modes of operation that imitate nature, is the specific characteristic of regenerative agriculture. The practice, although still a "niche", is gaining the attention of farmers because comparisons between conventional and regenerative farming have demonstrated that lower production costs (inexpensive seed, no synthetic inputs, combination of crops) and premium selling prices ("organic" standard) may produce higher net incomes for the farmers, despite lower yield.

Soil health implications – possible indicator: Number of farmers self-declaring "regenerative" at agricultural censuses Rotations, mixed linear crops, agroforestry, limited or no tillage, mixed crop and animal farming reduce synthetic inputs to the soil, although requiring more manpower and, possibly, mechanical operations.

Impact on soil function – possible indicators: Soil Organic Matter content and Agrobiodiversity Index The palette of operations that characterise "regenerative" agriculture are known to improve soil biodiversity and increase the amount of soil organic matter (of which soil organic carbon is the largest component). This in turn increases cation exchange capacity and water retention with positive benefits on fertility, water use efficiency and erosion control

- **Diversifying nutrition patterns**

Dietary habits are changing, with an increasing number of people shifting towards vegetarian, vegan or gluten free diets. The awareness of sustainability challenges is a major driver behind these changes, while health reasons are only part of the explanation: for instance, the majority of those on gluten-free diets have no medical necessity to do so. In this context, more ancient, super-nutritious grains such as quinoa and amaranth will be ever more used instead of wheat flour, and producers increasingly need to consider these lifestyle changes. As scientific and technological advances develop in the field of health and nutrition, more focus has been directed toward the emerging field of nutrigenomics, which entails the application of the human genome to nutrition and personal health to provide individual dietary recommendations. There is however an asymmetric development: healthier cooking methods on the one hand, a shift to packaged processed unhealthier food, especially in urban areas, on the other hand.

Soil Health and Food implications In liberal market systems, consumers are the most powerful stakeholders and thereby drive value chains. Demand will create the supply in such a system. Therefore, consumers decide over the soil practice with their purchases. Consumption can improve soil practices e.g. when reducing meat consumption, switching to local purchasers or by eating seasonal and regional food. Diversified nutrition patterns also diversify soil practices, resulting in the establishment of manifold certification, production and practice standards.

Impact on soil function Soil is an important resource for retailers, suppliers and farmers to react to diversifying consumer demands. Especially for local and organic agricultural product attributes, soil functions must be restored, maintained and improved. Other trends, that create demand on products from overseas, hold the risk to externalize the responsibility for soil functions to opaque production places.

- **Emerging new food chain risks**

With the increasing size of the world population, consumer demand for a wider variety of foods is growing, entailing a longer and more complex food chain. On the other hand, ensuring food safety and security in a highly globalized world presents increasingly difficult and often under-appreciated challenges for governments, commercial organizations, and individuals. The risks of unsafe food are substantial but can be difficult to quantify. Conflicts are a major driver of food insecurity and malnutrition. They reduce food availability, disrupt access to food and health care, and undermine social protection systems. Every famine in the modern era has been characterized by conflict. These conflicts are complex by nature. They can be triggered or amplified by climate-related natural disasters and the impact that they have on poverty eradication and food security. Natural disasters tend to trap vulnerable people, in particular, in a cycle of poverty because they are less resilient and lack coping capacity. It can be assumed that extreme weather events, caused by climate change, will further worsen the situation of these people.

Overall, the safety of product supply is important and requires new regulatory requirements, challenged by increased supply chain complexity. There is a need to refocus attention and to re-energize commitments on food safety, especially coordinated and cooperative actions and communications across borders. Better data and methods are needed to estimate the health impact of foodborne diseases and to guide response and prevention actions.

Soil Health and Food implications Food safety concerns are encouraging practices that simplify farms and landscapes. The results of the study of Karp et al. (2016) demonstrate that two practices – elimination of manure-based composts and removal of non-crop vegetation – are likely having negative impacts on arthropod biodiversity, pest control and soil quality. The authors suggest that growers may benefit from increased ecosystem services, without incurring food safety costs, by applying appropriately treated compost and maintaining semi-natural habitat. Co-managing fresh produce for food safety and conservation goals is possible and likely beneficial for nature and for growers.

Impact on soil function It is important to use the risk assessment before cultivation. For example, fields should be examined for possible problems that have occurred since the last harvest. The risk could be minimised by optimising the natural services provided by well managed vegetation, soil and water. Promoting healthy, balanced agricultural systems is a robust strategy to support public health. Co-management of food safety and conservation on the farm can be attained. The information here will equip growers to evaluate food safety risk factors on their farm and thoughtfully manage to minimize them. A written food safety plan, which describes and explains the farm's management practices, is an excellent step toward avoiding food safety problems.

- **Circularity of production**

Globalization has led to complex food supply chains across the world, all the way from raw material sourcing to disposal, through suppliers, manufacturers, retailers, consumers and other actors. The current linear model entails a variety of inefficiencies and sustainability challenges. For instance, transportation of food and feed to be consumed in the EU causes considerable greenhouse gas emissions. In a circular model of the value chain, materials are reused or recycled to minimize waste, there are no longer up- and downstreams, but a network of interactions and value exchanges (De Boer & Van Ittersum, 2018). Today's distribution networks are dominated by large producers, while a seamless integration of small producers can allow procurers to meet demands for locally sourced food and reduced-waste.

Food circles promote the consumption of safe, regionally grown food that encourages sustainable agriculture practices and helps maintain farmers and rural areas. The circular practice relies on spatial proximity and ideological parity of actors across all production, consumption and waste management activities. Advantages include better traceability and freshness of products, reduced packaging, improved relationships between farmers and consumers, and decreased environmental damage from agriculture and logistics. One disadvantage is that consumers may face constraints in accessibility of food from their local circles, due to climatic and seasonal limitations or higher prices.

Soil Health and Food implications Increasing interest in direct sale from farmer to customers has led to various innovations such as: a) Alternative Food Networks e.g. Food Coop, Community-Supported Agriculture (CSA), Self-Harvest Gardens, b) food circle buying clubs, c) seasonal food box subscriptions, and d) online farm shops. Stronger and more direct consumer-producer interactions have an impact on agricultural an soil practice e.g. by putting the priority on cultivating the vegetables in the most organic way possible, without mineral fertilisers or chemical crop protection. Non-contaminated vegetables have a very high priority.

Impact on soil function Circularity of production means replacing mineral fertilizers with increased input of organic waste and by-products into the soil for organic fertilization. Organic inputs generally beneficial for all soil functions. A great barriers lies in limited knowledge about elimination of pollutants, pathogens and other chemicals that may enter the soil and food system. In addition, when local supply substitutes products from far away, the effects of agricultural practice are more obvious and might lead to a more sustainable management of land. This can contribute to strengthen soils functions.

- **Towards Chemical Pesticide Free-Agriculture**

The use of chemical pesticides (herbicides, fungicides, insecticides) affect water and soil quality, biodiversity as well as human health via the consumption of food produced with the use of those chemical substances. Despite the fact that the approval of pesticides is subject to strict regulations in Europe, public concern about human and environmental health issues related to the persistence of pesticides and derivatives in water, soil and food is growing. The use of pesticides in Europe is still increasing, but research is increasing efforts to substitute the use of pesticides through biological regulations and smart farming technologies. The later could provide synergies with other soil related targets such as the provision of ecosystem services and biodiversity.

Soil Health and Food implications The use of bioherbicide and biopesticide strategies used for weed and pest controls through integrated weed and pest management systems. More monitoring and assessment on sustainable development associated with the transition from chemical (BAU) towards prevailed or only biological agricultural inputs are needed, incl. foci on plant health, resource use efficiency, biodiversity, human health, risks and costs

Impact on soil function Lower yields, however, associated higher ecosystem biodiversity, reduced human health risks, improvement of the pollination ecosystem service, mitigation of soil contamination

D. Targets and opportunities to soil health and food

- **Holistic policy making and civil society involvement**

The defining feature of today's environmental challenges is their complexity. As SOER (EEA 2015) points out, the challenges of the future are markedly different from those of the past:

- In their magnitude, as they threaten future access to basic environmental needs. They demand that we act now.
- In their origins, as they are embedded within our production and consumption patterns. They require a paradigm shift in our and in the world economy.
- In their interdependency. They require us to consider cross-sectoral synergies and mitigate trade-offs.
- In their global reach. They call for enhanced collaboration among countries

Looking at the challenges ahead, the EU needs to further increase its engagement and seek greater coordination among policies, among stakeholders, and among countries. Current EU Soil legislations are direct to 'prevent acceleration' of soil threats more than improving soil functions (Glæsner and all). Similarly, for land degradation "Most policies directed at addressing land degradation are fragmented and target specific, visible drivers of degradation within specific sectors of the economy, in isolation from other drivers. Land degradation is rarely, if ever, the result of a single cause and can thus only be addressed through the simultaneous and coordinated use of diverse policy instruments and responses at the institutional, governance, community and individual levels" (IPBES 2018).

- **The market prices: the hidden costs of food**

Today's consumption patterns are decisive for future disposal and environmental problems (e.g. material diversity and combinations). Consumption and environmental effects are often spatially decoupled, e.g. in the case of active pharmaceutical ingredients in the drinking water cycle and micro plastics in the oceans. Some effects are also temporally decoupled. The location, distribution, nature and dynamics of such creeping environmental effects are often only known in isolated cases. Individual consumption patterns are closely linked to traffic- and production-related environmental impacts. The consumption patterns of consumers with high income cause by far the greatest environmental impact. Especially meat production and consumption are inefficient uses of resources and contribute significantly to climate change. The nonchalant use of pesticides in industrial-scale agriculture may provide cheap food, but there are hidden costs to environmental protection, human health and biodiversity conservation. Many of these costs must be paid for by future generations, hidden in a complex network of international development, national security, health care, industrial meat production, organic farming, corporate responsibility, government subsidies, food aid and global commodity markets. The time dimension of hidden costs refers to hidden follow up costs, *where present operations cause a cost but transfer the date of the actual occurrence of that cost to the future (months, years, decades and centuries) or to another place.* Uncovering hidden costs, addressing them to their origin and implementing efficient measures helps society to apply the cost by cause principle and thereby increases justice in combined social, economic and ecological systems. Even if the impacts of hidden costs on soil functions are very complex and hard to comprehend, which explains why they are referred to as hidden costs. The more of these impacts are unhidden, the better environmental systems can be understood and managed.

- **Soil for sustainable food, feed and fibre yield levels**

Cultivation of plants on land underpins global food supply. Yields, which can be considered broadly, as food crops, feed crops including pasture for animal production, and fibre, which includes timber depend on resource supplies from soils**.** Soils are the incubator and supplier of nutrients, water and oxygen to plants, in addition to providing the structural support for growth. Maintaining production levels to feed a growing population cannot be taken for granted. Soils must be replenished with nutrients and water, with nutrient addition increasingly reliant on fertiliser from either finite resources (P) or energy intensive production (N). Working with in planetary limits is vital if we are to avoid breaking the food production system.

Among the future opportunities mentioned for improving food, feed and fibre yield:

- Creation of *closed loop systems for recovery of major nutrients, water and micronutrients* from low-grade farm and food wastes to reduce dependence on primary stocks and global markets (RSC, 2011)
- Development and application of *high sensitivity, high resolution biosignalling and sensor technologies to support precision agriculture and more sophisticated regulatory testing* (RSC, 2011)
- Increase the proportion of *soil less produced food* made available and consumed by society. (greenhouse, aquaponics, vertical gardening etc)

On the other hand, there is evidence of yield plateaus or abrupt decreases in rate of yield gain, including rice in eastern Asia and wheat in northwest Europe, which account for 31% of total global rice, wheat and maize production. (Grassini et al., 2013)

- **More nutritious and safe food - diet and food**

The Treaty of Amsterdam obliged EU to ensure "high level of human health protection (..) in the definition and implementation of all Community policies and activities" and health is now included as transversal requirement in the EU Treaty on the Functioning of the EU. As regard healthy diet strategies and roadmap adopted at EU level are:

- Strategy for Europe on Nutrition, Overweight and obesity related health issues (2007)
- EU Action Plan on Childhood Obesity 2014-2020
- WHO European food and Nutrition Action Plan 2015-2020

For diet, recommendations for populations and individuals should include the achievement of an energy balance and a healthy weight by the limitation of salt consumption, free sugars and total fats (possibly shifting fat consumption away from saturated fats to unsaturated fats and towards the elimination of trans-fatty acids), and a parallel increase in consumption of fruits, vegetable, and legumes, whole grains and nuts.

EAT- "Lancet Commission on Healthy Diets from Sustainable Food Systems" (EAT 2016) evaluated the shifting toward healthy diet as of one the three targets needed to meet the challenge of proving healthy food for 10 billions people by 2050 while creating a sustainable food production to ensure stable earth system. According to EAT 2016, healthy diets target would require to:

- Double the consumption of healthy food such as fruits, vegetables, legumes and nuts;
- Greater than 50% reduction in the global consumption of less healthy food such as added sugar and red meat (primarily by reducing excessive consumption in wealthier countries).

However, on the whole the "current EU food systems and policies are failing to address the root of unhealthy diets while austerity policies are further undermine the social safety net". The main question behind is how to make healthy food accessible to all. In 2015, 23.7% of EU citizens were at risks of social exclusion and 8.7% were affected by food insecurity in 2011 (IPES-Food panel: February 2019).

- **Soil contribution to the solution to the climate crises**

Soil is the largest terrestrial reservoir of soil carbon, preventing this from being released into the atmosphere is a major challenge. Furthermore, soil carbon is central to maintaining soil structure and retaining nutrients.

The 4 per mille initiative aims to increase soil carbon levels by restoring areas where carbon has been depleted from soils. Moreover, soils release other greenhouse gases such as nitrous oxide, and careful management is required to minimize this. The initiative, launched at COP21 in 2015, aims at an annual growth rate of 0.4% in the soil carbon stocks, or 4‰ per year, in the first 30-40 cm of soil and it would significantly reduce the CO_2 concentration in the atmosphere related to human activities. This growth rate is not a normative target for each country).

The 4 per mille number was based on a blanket calculation of the whole 2m global soil profile C stock, however the potential to increase SOC is mostly on managed agricultural lands. This initiative offers the opportunity to set realistic ambitions for agricultural and non-agricultural land. In addition, most studies on SOC sequestration only consider topsoil (up to 0.3m depth), as it is considered to be most affected by management techniques while it would be possible to consider 4 per mille in the top 1m+ of soils. A SWOT of this initiative is presented in the annex.

To monitor progress toward the target, indicator could be a combination of ground based survey, like LUCAS. Improvement may be possible using remote sensing of bare soil in winter to improve spatial coverage.

- **Soils to help us cope better with drought and floods**

Soil moisture controls the partitioning of moisture that arrives at the land surface into that which infiltrates and that which runs off. 'It acts as a shock absorber to extreme events by absorbing water, or moderating heat and cold waves. Soil moisture is a key variable of the climate system. It constrains plant transpiration and photosynthesis in several regions of the world, with consequent impacts on the water, energy and biogeochemical cycles. Moreover, it is a storage component for precipitation and radiation anomalies, inducing persistence in the climate system. Finally, it is involved in a number of feedbacks at the local, regional and global scales, and plays a major role in climate-change projections.' (Seneviratne et al., 2010). Soil moisture retention depends on soil texture and structure, moderated by soil organic carbon in temperate latitudes. One of the opportunity for this goal is to increase water retention in soils adding organic matter. Excess of N and P in soils limits the possibility of using external input of organic matter due to strict manure regulation. 'The availability of ground observations continues to be critical in limiting progress and should therefore strongly be fostered at the international level.' (Seneviratne, 2010).

Among the possible indicators to measure this goal are i) Sensor networks soil moisture and meteorology ii) remote sensing soil moisture iii) stream flows and groundwater iv) meteorological measurements, combined in a modelling framework.

- **Soils as a habitat for the diverse range of life**

For this goal, the world-wide framework is given by the Convention on Biological Diversity (CBD). The conclusion of the 10 Conference of Parties (COP) in 2010 - the 20 Aichi Biodiversity Targets set "Target 7: By 2020, areas under agriculture, […] are managed sustainably, ensuring conservation of biodiversity" (Techen, Helming, 2019, COP to CBD 2010). The conclusion of the 14 COP CBD in 2018 reported on the progress made for target 7: "promote the conservation and sustainable use of soil biodiversity, such as by contributing to the International Initiative for the Conservation and Sustainable Use of Soil

Biodiversity coordinated by the FAO; and improve enforcement and monitoring of sustainable forest management and the sustainability of timber trade, particularly in developing countries and tropical regions”. The target will not be achieved by 2020 - also because there is no sufficient progress in formulating and implementing respective national strategies on biological diversity. (COP to CBD 2018)

At EU level, soils are recognised in European and national strategies as a vital resource for biodiversity: natural diversity of soils which have evolved over the course of history, are typical of the region, and fulfil a range of functions for man and nature. They offer favourable living conditions for the location-typical species and biotic communities which live in, on and from the soils (National Biodiversity Strategies and Action Plan for Germany, 2007 cited in Techen, Helming, 2019). In May 2011, the European Union adopted a new strategy to halt biodiversity loss in the EU, restore ecosystems where possible, and step up efforts to avert global biodiversity loss (EC 2011). The Target 3 concerns agriculture and forestry contribution, in turn the contribution of land and soil management. In 2015, the Commission publish the Midterm Review of the EU biodiversity strategy (EC, 2015), concluding that there has not been significant progress toward Target 3.

Soils as a habitat for the diverse range of life are addressed in two of the nine objectives stressed in the proposal on the CAP after 2020 (COM(2018) 392 final): v) environmental care and vi) to preserve landscapes and biodiversity. However, no target levels are given.

Among the opportunities some of the practices identified to contribute to soil function of provision of biodiversity i) introduce Conservation Agriculture practices. Conservation agriculture (ECAF) emphasize positive effect of CA practices on soil biodiversity ii) introduce bio-corridors, protection/buffer strips, reduce field blocks iii) improve rotation iv) limitation the use of toxic inputs, to expand organic and integrated farming v) Prevent deforestation.

Among the possible indicator to measure progress toward this goal is the number of micro and macro organism in a volume of soil (occasionally measured, not surveyed regularly).

- **Soils to contribute to the reuse of waste while protecting and improving soil health – value chain: more for less**

In this area, it is possible to consider 3 types of waste which can be of interest in reuse for soil benefit: sewage and sludge (of water cleaning plants), bio-degradable municipal waste and coal combustion by-products (CCP).

The use of *sewage sludge in agriculture* is a common practice in Europe particularly with the objective to limit significantly its disposal in landfill (Directive 1999/31/EC). The use of sewage sludge is regulated by the Council Directive 86/278/EEC and its national transpositions, addressing the content of contaminants and the requirement of pretreatment (e.g. composting). Thus, we can state the target is to use as much as possible of the sewage sludge of resulting from municipal waste water treatment (Inglezakis et al. 2014].

The EU Member States are in the process of transposing the EU waste Directive (2018/851) which poses as target for the municipal waste reduction by 55%, 60% and 65% by 2025, 2030 and 2035 respectively or an alternative reduced rates by 5% points. If the content of bio-degradable waste in municipal waste is between 30% and 40 % (Mühle et al. 2009, Bölükbaş, Akıncı, 2018), this target puts pressure on eliminating this waste by composting it or using it as input in the bio-gas plants. Generally, we can regard the complete elimination of the municipal bio-degradable waste as a target for 2035, which in turn will meant production of a corresponding amount of compost and digestate to be used in agriculture and forestry

Coal combustion by-products (CCP) are used as soil improvers in many countries including the USA (James, Pandian, 2015, Cimitile, 2009); however, rarely in Europe. Most of CCP is used in the construction industry and about one third for re-cultivation and restoration of open cast mines or quarries (Feuerborn, 2011). Some authors question its use in agriculture because of toxicity (Cimitile, 2009), while others argue that the material is safe (Feuerborn, 2011), or even see its potential to reduce soil erosion (see www.flyash.info, University of Kentucky]. Evidently, the EU has no soil (re-use or improvement) related target. Thus, Question mark hangs over the CCP use in agriculture, but the re-cultivation of open cast mines or quarries seems to be very appropriate.
Among the possible indicators to measure these goals are

1. The share of no hazardous sewage sludge used in agriculture
    a. Monitored at farm level and reported – statistical survey
2. The share of bio-degradable municipal waste reused (composted, used in bio/gas plants) and the respective amount of compost and digestat produced and used in agriculture and forestry.
    a. Monitored at the municipal level and reported / a statistical survey

- **Soils to support to the greening of our towns and cities**

The EU aims to achieve 'no net land take by 2050' in line with the SDG. One clear way of limiting urban expansion is to make better use of the existing urban space. However, today land recycling and densification account for only a fraction — 13 % — of new developments, and land take continues in many EU countries (EEA). Urban growth is driving land-use change in Europe, with peri-urban areas developing at four times the rate of towns and cities (SCAR 2011). Integrated planning, particularly combining land use, mobility and transport, as well as the urban and regional dimensions, is one of the key instrument to promote compact urban development and increase environmental resilience.

EU is also committed to "provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities (SDG 11). The assessment carried out by EnRoute Project (JRC 2019) revealed that core cities in Europe are for about 40%, on average, covered with Urban Green Infrastructure (UGI). The amount of publicly accessible green space is estimated much lower at 2.45%, on average and while the accessibility to urban green space is high (18m^2 on average), it is unevenly distributed across European urban dwellers. It is also been estimated that 46% of functional urban area low capacity to mitigate floods. "EnRoute also assessed the current availability and condition of UGI and the benefits it delivers in almost 700 of Europe's functional urban areas (FUA) and core cities. The indicators used to assess UGI incorporate a variety of data and metrics: anthropogenic pressures, pollution levels, soil sealing, the amount and configuration of UGI, urban biodiversity, recreation opportunities and flood mitigation".(JRC 2019)

UGI plays a key role for reducing urban land degradation, contributing to climate change mitigation and adaptation while significantly improving quality of life. Opportunities related to this regards 'replanting with native species, green infrastructure development, remediation of contaminated and sealed soils, and wastewater treatment and river channel restoration. Landscape-level and ecosystem-based approaches that use, among others, restoration and sustainable land management techniques to enhance the provision of ecosystem services have proven effective in reducing flood risk and improving water quality for urban populations' (IPBES 2018).

The report "Common food polices" (IPES FOOD 2019) highlights the on-going social innovation in EU cities "they include short food chains and community supported agriculture; new ways of reducing waste; various types of urban agriculture; an inventive use of public procurement schemes; or new forms of sharing food within local communities. Cities and regions are emerging as major actors in these innovations, and new alliances are being formed between public entities, local entrepreneurs, and civil society groups.

Yet, there is a gap between policies developed at national and EU level, and those social, often citizens-led innovations: rather than encourage and reward local experimentation, top-down policies tend to homogenize, in the name of efficiency gains from economies of scale and standardization, or undistorted competition. It is urgent that the EU puts itself in the service of supporting diversity rather than uniformity".

E. REFERENCES

Acton DF, Gregorich L (1995) The health of our soils: toward sustainable agriculture in Canada.

Adewopo, J.B., VanZomeren, C., Bhomia, R.K., Almaraz, M., Bacon, A.R., Eggleston, E., Judy, J.D., Lewis, R.W., Lusk, M., Miller, B. and Moorberg, C., 2014. Top-Ranked Priority Research Questions for Soil Science in the 21 st Century. Soil Science Society of America Journal, 78(2), pp.337-347.

Aklin, M.; Mildenberger, M. (2018): Prisoners of the Wrong Dilemma: Why Distributive Conflict, Not Collective Action, Characterizes the Politics of Climate Change. In: SSRN Electronic Journal. DOI: 10.2139/ssrn.3281045.

AMR Review, 2015. Antimicrobials in agriculture and the environment: Reducing unnecessary use and waste. Chaired by Jim O'Neill, https://amrreview.org/sites/default/files/Antimicrobials%20in%20agriculture%20and%20the%20environment%20-%20Reducing%20unnecessary%20use%20and%20waste.pdf

Amundson R, Biardeau L (2018) Opinion: Soil carbon sequestration is an elusive climate mitigation tool. Proceedings of the National Academy of Sciences, 115, 11652-11656.

Amundson, R., and L., Biardeau, 2018. Soil carbon sequestration is an elusive climate mitigation tool. PNAS, 115(46), pp.11652–11656

Anderson, Colin R.; Maughan, Chris; Pimbert, Michel P. (2019): Transformative agroecology learning in Europe: building consciousness, skills and collective capacity for food sovereignty. In Agriculture and Human Values (Volume 36 Issue 3), pp. 531–547.

Artmann, Martina (2014): Assessment of soil sealing management responses, strategies, and targets toward ecologically sustainable urban land use management. In Ambio 43 (4), pp. 530–541. DOI: 10.1007/s13280-014-0511-1.

Barrington, Suzelle; Adhikari, Bijaya (2018): Production vs. consumption management for sustainable agricultural resources. In IJISD 12 (1/2), p. 183. DOI: 10.1504/IJISD.2018.089249.

Beacham, A. M.; Vickers, L. H.; Monaghan, J. M. (2018): Vertical farming. A summary of approaches to growing skywards. In: The Journal of Horticultural Science and Biotechnology 94 (3), pp. 277–283. DOI: 10.1080/14620316.2019.1574214.

BIOPRO Baden-Württemberg GmbH (Ed.): Digitisation in agriculture – from precision farming to farming 4.0 – Bioeconomy. Available online at https://www.biooekonomie-bw.de/en/articles/dossiers/digitisation-in-agriculture-from-precision-farming-to-farming-40, checked on 10/10/2019.

Bisoffi, Stefano (2019): A meta-analysis of recent foresight documents in support of the 5thSCAR Foresight Exercise. Study carried out under the Project"Support Action to a common agricultural and wider bioeconomy research agenda" (CASA)Topic SFS-25-2016. Available online at https://scar-europe.org/images/FORESIGHT/CASA-Study-Meta-Analysis-Foresight-SUB.pdf, checked on 11/13/2019.

Blum WE (2005) Functions of soil for society and the environment. Reviews in Environmental Science and Bio/Technology, 4, 75-79.

Bohstedt, John (2014): Food riots and the politics of provisions in world history. Brighton: IDS (IDS working paper, 444).

Bölükbaş, A., Akıncı, G. (2018) Solid waste composition and the properties of biodegradable fractions in Izmir City, Turkey: an investigation on the influencing factors. J Environ Health Sci Eng. 2018 Dec; 16(2): 299–311.

Boqvist, Sofia; Söderqvist, Karin; Vågsholm, Ivar (2018): Food safety challenges and One Health within Europe. In *Acta veterinaria Scandinavica* 60 (1), p. 1.

Bourgeais, Vincent; Agafitei, Lucian; Hrkal, Jakub (2016): European Health Interview Survey. Almost 1 adultin 6 in the EU is considered obese. Share of obesity increases with ageand decreases with education level. Edited by Eurostat (203/2016). Available online at https://ec.europa.eu/eurostat/documents/2995521/7700898/3-20102016-BP-EN.pdf/c26b037b-d5f3-4c05-89c1-00bf0b98d646, checked on 10/31/2019.

Bünemann EK, Bongiorno G, Bai Z et al. (2018) Soil quality–A critical review. Soil Biology and Biochemistry, 120, 105-125.

Bush, Ray; Martiniello, Giuliano (2017): Food Riots and Protest. Agrarian Modernizations and Structural Crises. In *World Development* 91, pp. 193–207. DOI: 10.1016/j.worlddev.2016.10.017.

Cagnarini C, Blyth E, Emmett BA et al. (2019) Zones of influence for soil organic matter dynamics: A conceptual framework for data and models. Global Change Biology.

Cagnarini, C., Blyth, E., Emmett, B.A., Evans, C.D., Griffiths, R.I., Keith, A., Jones, L., Lebron, I., McNamara, N.P., Puissant, J. and Reinsch, S., 2019. Zones of influence for soil organic matter dynamics: A conceptual framework for data and models. Global change biology.

Campbell, B. M.; Vermeuten, S.; Aggarwall, P. K.; Corner-Dolloff, C. A. (2016): Reducing risks to food security from climate change. In: Global Food Security, pp. 1–11, checked on 23/09/2019.

Certini G, Scalenghe R (2006) Soil formation on Earth and beyond: the role of additional soil-forming factors. Soils: Basic concepts and future challenges. Cambridge University Press, Cambridge, UK, 193-221.

Cimitile, M. (2009) Is Coal Ash in Soil a Good Idea? Scientific American. https://www.scientificamerican.com/article/coal-ash-in-soil/

Consultative Group on International Agricultural Research (CGIAR) (6/27/2019): Will climate change make us go hungry by 2050? Available online at https://ccafs.cgiar.org/news/media-centre/press-releases/will-climate-change-make-us-go-hungry-2050#.XYxwfEexVaQ, checked on 26/09/2019.

Costello, H. (2019): Global Gluten Free Food Market (by Products, Distribution Channels, Regional Analysis), Mergers & Acquisitions, Key Company Profiles - Forecast to 2025. Orbis Research (519010). Available online at https://www.marketwatch.com/press-release/global-gluten-free-food-market-by-products-distribution-channels-regional-analysis-mergers-and-acquisitions-key-company-profiles-forecast-to-2025-2019-05-31,checked on 19/09/2019.

Daniel S. Karp, Rebekah Moses, Sasha Gennet, Matthew S. Jones, Shimat Joseph,Leithen K. M'Gonigle, Lauren C. Ponisio, William E. Snyder, Claire Kremen (2016): Agricultural practices for food safety threaten pest control services for fresh produce. Journal of Applied Ecology, 53, 1402–1412.

Davy, Benjamin (2012 // 2016): Land Policy. Planning and the Spatial Consequences of Property. 1st Edition. London, UK: Routledge.

De Boer I, van Ittersum M (2018) Circularity in agricultural production. Wageningen University and Research

Deloitte (Ed.) (2018): Global Power of Retailing 2018. Transformative change, reinvigorated commerce. Available online at https:// www2.deloitte.com/content/dam/Deloitte/at/Documents/ about-deloitte/global-powers-of-retailing-2018.pdf, checked on 23/09/2019.

Deutsches Institut für Wirtschaftsforschung (Ed.) (2017): The power of retailers (DIW Econ Economic Bulletin, 3). Available online at https://diw-econ.de/wp-content/uploads/2017/04/ Bulletin-No.3-Buying-Power-in-the-German-Retailing-Sector.pdf, checked on 20/09/2019.

Dominati E, Patterson M, Mackay A (2010) A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics, 69, 1858-1868.

EAT-Lancet Commission on "Healthy Diets From Sustainable Food Systems" Summary for policy makers https://eatforum.org/content/uploads/2019/01/EAT-Lancet_Commission_Summary_Report.pdf . thelancet.com/commissions/EAT

EC (2018) Land cover use (https://ec.europa.eu/agriculture/sites/agriculture/files/statistics/facts-figures/land-cover-use.pdf).

EC Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture.

EC Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste.

EC DIRECTIVE (EU) 2018/851 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2008/98/EC on waste.

EC-1165 (2006) The Impact Assessment. (SEC (2006) 1165

EC-231 (2006) Soil Thematic Strategy. COM (2006) 231.

EC-232 (2006) The proposal for a framework Directive. (COM(2006) 232)

EC-46 (2012) The implementation of the Soil Thematic Strategy and ongoing activities', COM(2012) 46.

EC-620 (2006) Analysis of the economic, social and environmental impacts. SEC(2006)620).

EC (2018) "Food 2030 – Proofing our food systems through Research and Innovation"

Edvardsson K, Hansson S (2005) When is a goal rational? Social Choice and Welfare, 24, 343-361.

Eigenbrod, C.; Gruda, N. (2015): Urban vegetable for food security in cities. A review. In: Agron. Sustain. Dev. 35 (2), pp. 483–498. DOI: 10.1007/s13593-014-0273-y.

European Commission (2015): EIP-AGRI Focus Group on Precision Farming: Final report. Available online at https://ec.europa.eu/ eip/agriculture/sites/agri-eip/files/eip-agri_focus_group_on_precision_farming_final_report_2015.pdf.

European Commission (2016): Agricultural knowledge and innovation systems towards the future. A foresight paper. Standing Committee on Agricultural Research (SCAR). Strategic Working Group AKIS-3 Report. Luxembourg: Publications Office of the European Union (EUR, 27692 EN).

European Commission (2016): Agricultural knowledge and innovation systems towards the future. A foresight paper. Standing Committee on Agricultural Research (SCAR). Strategic Working Group AKIS-3 Report. Luxembourg: Publications Office of the European Union (EUR, 27692 EN).

European Commission (Ed.) (2018): World Urbanization Prospects: The 2018 Revision, Online Edition. WUP2018-F02-Proportion_Urban.xls. Available online at https://population.un.org/wup/Download/, checked on 11/13/2019.

European Court of Auditors (2018) Special report n°33/2018: Combating desertification in the EU: a growing threat in need of more action https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=48393

Eyerund, T.; Neligan, A. (2017): Verschwenderische Generationen X und Y. Institut der deutschen Wirtschaft Köln (56.2017). Available online at https://www.iwkoeln.de/fileadmin/publikationen/2017/350865/IW-_Kurzbericht_56_2017_Lebensmittelverschwendung.pdf, checked on 19/09/2019.

FAO (2018): Agricultural trade, climate change and food security. Rome: Food and Agriculture Organization of the United Nations (The state of agricultural commodity markets, 2018).

FAO, 2015. Global Forest Resources Assessment 2015. FAO Forestry Paper No. 1. UN Food and Agriculture Organization, Rome (2015)

FAO, 2017. E-agriculture in Action: Blockchain for Agriculture, Ed. by Gerard Sylvester. ISBN 978-92-5-131227-8

Fao-Itps (2015) Status of the world's soil resources (SWSR)–main report. Food and agriculture organization of the United Nations and intergovernmental technical panel on soils, Rome, Italy, 650.

Feuerborn, H-J, (2011) Coal combustion products in Europe - an update on production and utilisation standardisation and regulation. WORLD OF COAL ASH Conference in Denver, Colorado--MAY 9-12, 2011. http://www.flyash.info/2011/007-feuerborn-2011.pdf

Flanagan, Katie (2019): A 10-Step Plan for the World to Cut Food Loss and Waste in Half By 2030. World Resources Institute. Available online at https://www.wri.org/blog/2019/08/10-step-plan-world-cut-food-loss-and-waste-half-2030, checked on 9/24/2019.

Food and Agricultural Organization of the United Nations (2019): Key facts on food loss and waste you should know! Available online at http://www.fao.org/save-food/resources/keyfindings/en/, checked on 10/9/2019.

Food and Agricultural Organization of the United Nations; World Bank (Eds.) (2019): Population density (people per sq. km of land area). Available online at https://data.worldbank.org/indicator/EN.POP.DNST, checked on 11/19/2019.

Food and Agriculture Organization of the United Nations (2013): FAO Factsheet: Food wastage Footprints. Available online at http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_FOOD-WASTAGE.pdf, checked on 19/09/2019.

Food and Agriculture Organization of the United Nations (2019b): Save Food: Global Initiative on Food Loss and Waste Regulation Key facts on food loss and waste you should know. Available online at http://www.fao.org/save-food/resources/keyfindings/ en/, checked on 19/09/2019.

Food and Agriculture Organization of the United Nations (2019c): SDG Indicator 2.1.1 -Prevalence of undernourishment. Available online at http://www.fao.org/sustainable-development-goals/indicators/211/en/, checked on 19/09/2019.

Food and Agriculture Organization of the United Nations (2019d): SDG Indicator 2.1.2 -Severity of food insecurity. Available online at http://www.fao.org/sustainable-development-goals/indica-tors/212/en/, checked on 19/09/2019.

Food and Agriculture Organization of the United Nations (2019e): The state of food security and nutrition in the world. Rome.

Foodsharing.de (Ed.): foodsharing rettet Lebensmittel! gemeinschaftlich, nachhaltig & wertschätzend. foodsharing ist und bleibt kostenfrei. Available online at https://foodsharing.de/, checked on 10/28/2019.

Franco, J. C.; Borras Jr., S. M.; Monsalve Suárez, S. (2015): Land and food sovereignty. In: Third World Quarterly 36, pp. 600–617. DOI: 10.1080 / 01436597.2015.1029225.

German Environment Agency (11/18/2019): Immer mehr Verpackungsmüll. Neuer Höchststand in Deutschland mit 18,7 Millionen Tonnen Verpackungsabfällen jährlich. UBA-Verpackungsexperte Gerhard Kotschik über die aktuellen Zahlen und den Handlungsbedarf. Available online at https://www.umweltbundesamt.de/immer-mehr-verpackungsmuell, checked on 11/19/2019.

Giannakis, Elias; Bruggeman, Adriana (2015): The highly variable economic performance of European agriculture. In Land Use Policy 45, pp. 26–35. DOI: 10.1016/j.landusepol.2014.12.009.

Goddek, S.; Joyce, A.; Kotzen, B. (2019): Aquaponics Food Production Systems. Combined Aquaculture and Hydroponic Production Technologies for the Future. 1st ed. 2019. Available online at https://doi.org/10.1007/978-3-030-15943-6.

Graeub, Benjamin E.; Chappell, M. Jahi; Wittman, Hannah; Ledermann, Samuel; Kerr, Rachel Bezner; Gemmill-Herren, Barbara (2016): The State of Family Farms in the World. In World Development 87, pp. 1–15.

Grand View Research (2019a): Precision Farming/Agriculture Market Size, Share & Trends Analysis Report By Offering (Hardware, Software, Services), By Application (Yield Monitoring, Irrigation Management) And Segment Forecasts, 2019 - 2025 (GVR-168038-376-8). Available online at https://www.grandviewresearch.com/industry-analysis/precision-farming-market, checked on 10/09/2019.

Green *et al.,* 2018. Sustainable Soil Management. DCA Report No. 121, electronic version 978-87-93643-55-0.

Gustavsson, Jenny; Cederberg, Christel; Sonesson, Ulf (2011): Global food losses and food waste. Extent, causes and prevention ; study conducted for the International Congress Save Food! at Interpack 2011, [16 - 17 May], Düsseldorf, Germany. Rome: Food and Agriculture Organization of the United Nations. Available online at www.fao.org/3/a-i2697e.pdf, checked on 5/27/2019.

Hasegawa, T.; Fujimori, S.; Havlík, P.; et al. (2018): Risk of increased food insecurity under stringent global climate change mitigation policy. In: Nature Clim Change 8, pp. 699–703. DOI: 10.1038/s41558-018-0230-x.

Helming K, Daedlow K, Paul C, Techen A, Bartke S, Bartkowski B, Kaiser DB, Wollschläger U, Vogel HJ. 2018. Managing soil functions for a sustainable bioeconomy – Assessment framework and state of the art. Land Degradation & Development 29:3112-3126.

HLPE. 2019. Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome

IBP, Inc. (2015): Cuba Investment and Business Guide Volume 1 Strategic and Practical Information // Cuba investment and businessguide. Strategic and practical information: Intl Business Pubns Usa.

Inglezakis, V. J., . Zorpas A.A., Karagiannidis A. Samaras, P., Voukkali, I. Sklari, S. (2014) European Union Legislation on Sewage Sludge. Fresenius Environmental Bulletin, Volume 23 – No 2a. 2014

IPBES. 2016. Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 36 pages

IPBES (2018) Summary for policymakers of the IPBES assessment report on land degradation and resportation

IPCC. 2019. Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)].

IPES-Food. 2017. Too big to feed: Exploring the impacts of mega-mergers, concentration, concentration of power in the agri-food sector. www.ipes-food.org

IPES 2018 "Toward a common food policy for the EU" http://ipes-food.org/_img/upload/files/CFP_FullReport.pdf

James J., Pandian, P. K. (2015) Soil Stabilization as an Avenue for Reuse of Solid Wastes: A Review. Acta Technica Napocensis: Civil Engineering & Architecture Vol. 58, No. 1

Jechalke et al., 2014. Fate and effects of veterinary antibiotics in soil, https://doi.org/10.1016/j.tim.2014.05.005

Jeffs, C. (2018): E-commerce competition enforcement guide. First edition. London, UK: Global Competition Review, Law Business Research Ltd (GCR Insight).

Jnawali, P.; Kumar, V.; Tanwar, B. (2016): Celiac disease: Overview and considerations for development of gluten-free foods. In: Food Science and Human Wellness (5 (4)), pp. 169–176, checked on 23/09/2019.

Jo Ann Baumgartner, Dave Runsten (2011): Farming with food safety and conservation in mind. https://producesafetyalliance.cornell.edu/sites/producesafetyalliance.cornell.edu/files/shared/documents/Baumgartner_WFA-CAFF_brochure.pdf, checked on 11/19/2019.

Joosse, Sofie; Grubbström, Ann (2017): Continuity in farming - Not just family business. In Journal of Rural Studies 50, pp. 198–208. DOI: 10.1016/j.jrurstud.2016.11.018.

JRC (2019) Enhancing Resilience Of Urban Ecosystems through Green Infrastructure (EnRoute)

Jurgilevic, A.; Birge, T.; Kentala-Lethonen, J.; Korhonen-Kurki, K.; Pietikäinen, J.; Saikku, L.; Schösler, H. (2016): Transition towards Circular Economy in the Food System. In: Sustainability 8 (1), 69. DOI: 10.3390 / su8010069.

Keenan RJ, Reams GA, Achard F, de Freitas JV, Grainger A, Lindquist E. (2015). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. Forest Ecology and Management 352 (2015) 9–20

Keesstra SD, Bouma J, Wallinga J et al. (2016) The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil.

Klein A-M, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C and Tscharntke T. 2006. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. B.

Kumar *et al., 2005. Antibiotic Uptake by Plants from Soil Fertilized with Animal Manure, DOI: 10.2134/jeq2005.0026*

LaCanne CE and Lundgren JG. 2018. *Regenerative agriculture: merging farming and natural resource conservation profitably*. PeerJ **6**:e4428; DOI 10.7717/peerj.4428

Lange, Peter de (2011): Urban Agriculture in Amsterdam. Understanding the recent trend in food production activities within the limits of a developed nation's capital. Master Thesis. Available online at https://areeweb.polito.it/didattica/UPWARD/dwd/agricolture/amsterdam.pdf, checked on 11/13/2019.

Le Mouël, C.; Forslund, A. (2017): How can we feed the world in 2050? A review of the responses from global scenario studies. In European Review of Agricultural Economics 44 (4), pp. 541–591. DOI: 10.1093/erae/jbx006.

Li, G.; Sun, G.-X.; Ren, Y.; Luo, X.-S.; Zhu, Y.-G. (2018): Urban soil and human health: a review. In European Journal of Soil Science (69), pp. 196–215, checked on 11/6/2019.

Linsner *el* al., 2019. Blockchain in Agriculture 4.0 - An Empirical Study on Farmers Expectations towards Distributed Services based on Distributed Ledger Technology, DOI 10.1145/3340764.3340799

Lipinski, B.; Hanson, C.; Lomax, J.; Kitinoja, L.; Waite, R.; Searchinger, T. (2013): Reducing Food Loss and Waste. Creating a Sustainable Food Future, Installment Two. World Resources Institute. Available online at https://wriorg.s3.amazonaws.com/ s3fs-public/reducing_food_loss_and_waste.pdf.

Loboguerrero, Ana Maria; Campbell, Bruce; Cooper, Peter; Hansen, James; Rosenstock, Todd; Wollenberg, Eva (2019): Food and Earth Systems. Priorities for Climate Change Adaptation and Mitigation for Agriculture and Food Systems. In Sustainability 11 (5), p. 1372. DOI: 10.3390/su11051372.

Loboguerrero, Ana Maria; Campbell, Bruce; Cooper, Peter; Hansen, James; Rosenstock, Todd; Wollenberg, Eva (2019): Food and Earth Systems. Priorities for Climate Change Adaptation and Mitigation for Agriculture and Food Systems. In Sustainability 11 (5), p. 1372. DOI: 10.3390/su11051372.

Lynch, J.; Meter, K.; Robles-Schrader, G.; Goldenberg, M. P.; Bassler, E.; Chusid, S.; Jansen Austin, C. (2015): Exploring Economic and Health Impacts of Local Food Procurement. Illinois Public Health Institute. Available online at https://www.crcworks.org/EHimpacts.pdf.

Marangon, F.; Tempesta, T.; Troiano, S.; Vecchiato, D. (2016): Toward a better understanding of market potentials for vegan food. A choice experiment for the analysis of breadsticks preferences. In: Agriculture and Agricultural Science Procedia (8), pp. 158–166, checked on 23/09/2019.

MarketsandMarkets Research Private Ltd (2019): Plant-based Meat Market by Source, Product, Type, Process And Region - Global Forecast to 2025. Available online at https://www.marketsandmarkets.com/Market-Reports/plant-based-meatmarket-44922705.html?gclid=Cj0KCQjwzozsBRCNARIsAEM9kBPbomC5V3-E1DQjoO6ESrMLsXtjVr-PWY6v3MWvjVIO2s7ZMMHCpAcaArghEALw_wcB, checked on 19/09/2019.

Martinez, S.; Hand, M.; Da Pra, M.; Pollack, S.; Ralston, K.; Smith, T.; Vogel, S.; Clark, S.; Lohr, L.; Low, S.; Newman, C. (2010): Local Food Systems. Concepts, Impacts, and Issues. U.S. Department of Agriculture, Economic Research Service (ERR, 97).

Masson-Delmotte, V.; Zhai, P.; Pörtner, H.-O.; et al. (2018): Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Geneva, Switzerland: IPCC (Special report).

McMichael, P. (2012): The land grab and corporate food regime restructuring. In: The Journal of Peasant Studies 39 (3-4), pp. 681–701. DOI: 10.1080/03066150.2012.661369

Menn, C. (2017): Die Foodsharing-Bewegung. Übriggebliebene Lebensmittel sichern und teilen. Bundeszentrum für Ernährung. Available online at https://www.bzfe.de/inhalt/die-foodsharing-bewegung-31533.html, checked on 19/09/2019.

Minasny B, Malone BP, Mcbratney AB et al. (2017) Soil carbon 4 per mille. Geoderma, 292, 59-86.

Minasny, B., Malone, B.P., McBratney, A.B., Angers, D.A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z.S., Cheng, K., Das, B.S. and Field, D.J., 2017. Soil carbon 4 per mille. Geoderma, 292, pp.59-86.

Moller, Björn; Voglhuber-Slavinsky, Ariane; Dönitz, Ewa; Rosa, Aaron (2019): 50 trends influencing Europe's food sector by 2035. Edited by Fraunhofer ISI. Karlsruhe.

Montanarella L (2015) Agricultural policy: Govern our soils. Nature News, 528, 32.

Mühle S, Balsam I, Cheeseman CR.(2009) Comparison of carbon emissions associated with municipal solid waste management in Germany and the UK. Resour Conserv Recy. 2009;54:793–801. doi: 10.1016/j.resconrec.2009.12.009

OECD/FAO (2019): OECD-FAO Agricultural Outlook 2019-2028 // OECD-FAO agricultural outlook 2019-2028. Paris: OECD Publishing; Food and Agriculture Organization of the United Nations (OECD-FAO agricultural outlook), checked on 10/30/2019.

Omnia Precision (2019): Connecting Agronomy and Precision Farming. Available online at https://www.omniaprecision.co.uk/, checked on 23/09/2019.

Opitz, Ina; Zoll, Felix; Doernberg, Alexandra; Specht, Kathrin; Siebert, Rosemarie; Piorr, Annette; Berges, Regine; Dönitz, Ewa; Warnke, Philine (2017): Alternative food networks at the urban-rural interface. agrathaer GmbH and Leibniz Centre for Agricultural Landscape Research (ZALF)

Orgiazzi A, Ballabio C, Panagos P, Jones A, Fernández‐Ugalde O (2018) LUCAS Soil, the largest expandable soil dataset for Europe: a review. European Journal of Soil Science, 69, 140-153.

Osmanski, S. (2019): Eating locally grown food is good for your body and the environment. World Economic Forum. Available online at https://www.weforum.org/agenda/2019/08/this-is-how-create-sustainable-version-agriculture/, checked on 10/9/2019.

Panagos P, Ballabio C, Lugato E, Jones A, Borrelli P. 2017. Condition of agricultural soil: Factsheet on soil erosion, EUR 29020, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-77328-0, doi:10.2760/728794, JRC110011

Pankhurst C, Doube B, Gupta V (1997) SR 1997. Biological Indicators of Soil Health: Synthesis. Biological Indicators of Soil Health. Pankhurst, CE, Doube, BM & Gupta, VVSR,(eds). CAB International, 419-435.

Rae, Alasdair (2018): Think your country is crowded? These maps reveal the truth about population density across Europe. Available online at http://theconversation.com/think-your-country-is-crowded-these-maps-reveal-the-truth-about-population-density-across-europe-90345.

Recanati, F.; Maughan, C.; Pedrotti, M.; Dembska, K.; Antonelli, M. (2019): Assessing the role of CAP for more sustainable and healthier food systems in Europe. A literature review. In The Science of the total environment 653, pp. 908–919.

Richter DD, Bacon AR, Mobley ML et al. (2011) Human-Soil Relations are Changing Rapidly: Proposals from SSSA's Cross-Divisional Soil Change Working Group. Soil Science Society of America Journal, 75, 2079-2084.

Robinson D (2015) Moving toward data on soil change. Science, 347, 140.

Robinson DA, Emmett BA, Reynolds B et al. (2012) Soil natural capital and ecosystem service delivery in a world of global soil change. Soils and food security, 41-68.

Robinson DA, Seaton F, Sharps K et al. (2018) Oxford Research Encyclopedia of Environmental Science.

Roe, S.; Streck, C.; Weiner, P.-H.; Obersteiner, M.; Frank, S. (2017): How Improved Land Use Can Contribute to the 1.5°C Goal of the Paris Agreement. Working Paper prepared by Climate Focus and the International Institute for Applied Systems Analysis, checked on 09/10/2019.

Romig D, Garlynd M, Harris R (1996) Farmer-based assessment of soil quality: a soil health scorecard. In: Methods for Assessing Soil Quality. (eds Doran J, Jones A) pp Page., Soil Science Society of America, Madison, WI, pp. 39–60.

Sandström, Vilma; Valin, Hugo; Krisztin, Tamás; Havlík, Petr; Herrero, Mario; Kastner, Thomas (2018): The role of trade in the greenhouse gas footprints of EU diets. In Global Food Security 19, pp. 48–55. DOI: 10.1016/j.gfs.2018.08.007.

Santeramo, F. G.; Carlucci, D.; Devitiis, B. de; Seccia, A.; Stasi, A.; Viscecchia, R.; Nardone, G. (2017): Emerging trends in European food, diets and food industr. Munich Personal RePEc Archive. Available online at https://mpra.ub.uni-muenchen.de/82105/, checked on 23/09/2019.

Schierhorn, C. D. (2018): Why Gluten-Free Is Here to Stay. Edited by Food Technology Magazine. Available online at https://www.ift.org/news-and-publications/food-technology-magazine/issues/2018/august/features/gluten-free-is-here-to-stay, checked on 10/10/2019.

Schrijver, R. (2016): Precision agriculture and the future of farming in Europe. Scientific foresight study: study. Brussels: European Parliament, checked on 19/09/2019.

Seneviratne SI, Lüthi D, Litschi M, Schär C (2006) Land–atmosphere coupling and climate change in Europe. Nature, 443, 205.

Seneviratne, S.I., Corti, T., Davin, E.L., Hirschi, M., Jaeger, E.B., Lehner, I., Orlowsky, B. and Teuling, A.J., 2010. Investigating soil moisture–climate interactions in a changing climate: A review. Earth-Science Reviews, 99(3-4), pp.125-161.

Smidt, Samuel J.; Tayyebi, Amin; Kendall, Anthony D.; Pijanowski, Bryan C.; Hyndman, David W. (2018): Agricultural implications of providing soil-based constraints on urban expansion. Land use forecasts to 2050. In Journal of environmental management 217, pp. 677–689. DOI: 10.1016/j.jenvman.2018.03.042.

Smithers, R. (2018): Third of Britons have stopped or reduced eating meat -report. Edited by The Guardian. Available online at https://www.theguardian.com/business/2018/nov/01/third-of-britons-have-stopped-or-reduced-meat-eating-vegan-vegetarian-report, checked on 10/10/2019.

Soto, I.; Balafoutis, A.; Barnes, A.; Beck, B.; Eory, V.; Fountas, S.; Gómez-Barbero, M.; Sánchez, B.; van der Wal, T.; Vangeyte, J. (2019): The contribution of precision agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU. Luxembourg: Publications Office of the European Union (EUR, Scientific and technical research series, 29320).

Specht, Kathrin; Siebert, Rosemarie; Hartmann, Ina; Freisinger, Ulf B.; Sawicka, Magdalena; Werner, Armin et al. (2014): Urban agriculture of the future. An overview of sustainability aspects of food production in and on buildings. In Agric Hum Values 31 (1), pp. 33–51. DOI: 10.1007/s10460-013-9448-4.

Steffan, J. J.; Brevik, E. C.; Burgess, L. C.; Cerdà, A. (2018): The effect of soil on human health: an overview. In European Journal of Soil Science (69), pp. 159–171.

Stolte J, Tesfai M, Oygarden L et al. (2016) Soil threats in Europe: status, methods, drivers and effects on ecosystem services: deliverable 2.1 RECARE project. pp Page, European Commission DG Joint Research Centre.

Surminski, S.; Bouwer, L. M.; Linnerooth-Bayer, J. (2016): How insurance can support climate resilience. In: Natural Climate Change 6, pp. 333–334. DOI: 10.1038/nclimate2979.

Techen A, Helming K. 2017. Pressures on soil functions from soil management in Germany. A foresight review. Agron. Sustain. Dev. 37:64 DOI: 10.1007/s13593-017-0473-3

The Lancet Planetary Health (2018): Environmental racism. Time to tackle social injustice. In *American Journal of Public Health* 2 (11), e462. DOI: 10.1016/S2542-5196(18)30219-5.

Thiele, Marlene (2019): Wie Frankreich gegen den achtlosen Umgang mit Essen kämpft. Sueddeutsche Zeitung. Available online at https://www.sueddeutsche.de/wirtschaft/lebensmittel-verschwendung-containern-1.4331886, updated on 2/17/2019, checked on 10/9/2019.

Tittonell P. 2014. Ecological intensification of agriculture — sustainable by nature. Current Opinion in Environmental Sustainability 8, 53-61. https://doi.org/10.1016/j.cosust.2014.08.006

Tóth G, Hermann T, Da Silva MR, Montanarella L (2018) Monitoring soil for sustainable development and land degradation neutrality. Environmental monitoring and assessment, 190, 57.

United Nations Department of Economic and Social Affairs (Ed.) (2018): 68% of the world population projected to live in urban areas by 2050, says UN. Available online at https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html, updated on 5/16/2018, checked on 11/13/2019.

van der Meulen, N.; Wiesel, J. (Eds.) (2017): Culinary Turn: Transcript Verlag (Aesthetic Practice of Cookery). Available online at https://www.jstor.org/stable/j.ctv1wxt0c.8.

Van Woensel L, Kurrer C and Tarlton J. 2016. Precision agriculture and the future of farming in Europe - Scientific Foresight Study. Scientific Foresight Unit, EPRS. IP/G/STOA/FWC/2013-1/Lot 7/SC5, December 2016.

Vanbergen AJ and the Insect Pollinators Initiative. 2013. Threats to an ecosystem service: pressures on pollinators. Front Ecol Environ 11(5): 251–259, doi:10.1890/120126

Verkerk, Pieter J.; Lindner, Marcus; Pérez-Soba, Marta; Paterson, James S.; Helming, John; Verburg, Peter H. et al. (2018): Identifying pathways to visions of future land use in Europe. In *Reg Environ Change* 18 (3), pp. 817–830. DOI: 10.1007/s10113-016-1055-7.

Wagga C, Bendera SF, Widmerc F and van der Heijdena MGA. 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. PNAS, 111 (14), 5266–5270

Warnke, Philine; Dönitz, Ewa; Opitz, Ina; Zoll, Felix; Doernberg, Alexandra; Specht, Kathrin; Siebert, Rosemarie; Piorr, Annette; Berges, Regine (2017): Szenarien zur Zukunft der Nahrungsmittelversorgung: Chancen und Herausforderungen für alternative Versorgungsnetzwerke. Fraunhofer ISI.

Wced SWS (1987) World commission on environment and development. Our common future, 17, 1-91.

Westra, Laura; Gray, Janice; Gottwald, Franz-Theo (2017): The Role of Integrity in the Governance of the Commons. Governance, Ecology, Law, Ethics: Springer; Springer International Publishing. Available online at https://www.springer.com/gp/book/9783319543918.

Whiting, Alex (2018): Cities are planting more trees to fight climate change and improve healthy living. Edited by World Economic Forum. Available online at https://www.weforum.org/agenda/2018/12/cities-are-planting-more-trees-to-curb-wild-weather-and-boost-healthy-living-ec92b137-4610-4871-a341-0c10ea1b3954, checked on 11/13/2019.

Whitmore, A.P., Kirk, G.J.D., Rawlins, B.G., 2015. Technologies for increasing carbon storage in soil to mitigate climate change. Soil Use Manag. 31, 62–71.

Worosz, M. R.; Wilson, N. L. W.; WOROSZ, M. R.; WILSON, N. L.W. (2012): A Cautionary Tale of Purity, Labeling and Product Literacy in the Gluten-Free Marke // A Cautionary Tale of Purity, Labeling and Product Literacy in the Gluten-Free Market. In: The Journal of Consumer Affairs 46 (2), pp. 288–318. DOI: 10.1111/j.1745-6606.2012.01230.x.

Zhao, C.; Liu, B.; Piao, S.; et al. (2017): Temperature increase reduces global yields of major crops in four independent estimates. In: Proceedings of the National Academy of Sciences of the United States of America 114 (35), pp. 9326–9331. DOI: 10.1073/pnas.1701762114.

F. ANNEX - Soil Organic Carbon

This analysis for the 4 per mille target is provided to capture some of the concerns and opportunities raised in a limited set of literature (Amundson & Biardeau, 2018, Cagnarini *et al.*, 2019, Minasny *et al.*, 2017, Whitmore *et al.*, 2015). It does not presuppose any particular socio-economic scenarios, nor does it deal with legislation. Carbon is highlighted here, as it is a current focus of research and used as an indicator for the SDGs. However, Amundson and Biardeau (2018) opine, '*that the current emphasis on carbon sequestration as the primary goal—with ancillary improvements in water management, soil erosion, and food security—seems almost inverted in its prioritization.*'

Concern	**Opportunity**
Goal / Target	
The 4 per mille number was based on a blanket calculation of the whole global soil profile C stock, however the potential to increase SOC is mostly on managed agricultural lands.	Set realistic ambitions for agricultural and non-agricultural land.
We found that most studies on SOC sequestration only consider topsoil (up to 0.3m depth), as it is considered to be most affected by management techniques.	Consider 4 per mille in the top 1m+ of soils
Addition of SOC in degraded land may only account for an offset between 20–35% of global GHG emissions.	Investigate other land uses and working with nature to increase belowground stores.
Environmental	
Excess of N and P in soils limits the possibility of using external input of organic matter due to strict manure regulation.	Develop holistic management to reduce N&P allowing for SOM application to land.
Societal cultural	
Society sees 4 per mille as a solution to GHG emissions and is fatigued by climate change, reduces efforts to reduce emissions.	Educate that 4 per mille is a finite solution in time and space for climate change mitigation and that long-term solutions to decrease greenhouse gas emissions should remain among the policymakers' priorities.
Many farmers, even those who practice innovative conservation methods, are suspicious of, and even hostile to, environmentally motivated academics and the perceived government intervention that will follow with any environmental initiatives.	Knowledge Exchange
Some farmers reject the reality that humans are causing climate change and that fossil fuel is inherently a problematic energy source. In	

particular, farmers are skeptical of nonfarmer experts, who are inexperienced or unaware of the economic and regulatory challenges that they face.	
Land tenure, Renters may have less financial incentive to invest in conservation programs that have long-term payoffs or benefits	
Offsite, older or urban landowners may fail to understand or have any immediate interest in conservation programs on land they own	
Economic	
Farming for carbon reduces productivity and income	Carbon markets, legislation to correct market failure
Conversion from tillage systems to permanent Grassland in UK, the introduction of woodland, growing biomass crops and the introduction of rotational grass could all lead to substantial initial carbon sequestration rates but the stocks would settle to a new equilibrium after 50–100 y. These practices would also lead to a loss of agricultural production.	Financial incentives for landowners. Ensure that we are not simply outsourcing the problem to less well-developed countries. Need to understand trade-offs.
National scale soil monitoring stops due to reductions in funding meaning areas of loss and gain remain unknown and not verified	Maintain national soil change monitoring
Peat drainage or extraction is still viewed as acceptable, offsetting gains from other sectors.	Carefully consider energy policy, investigate alternative sources of energy
The cost of capturing carbon via these existing Natural Resources Conservation Service (NRCS) programs is too high. Presently estimated to range between \$32 and \$442 per ton of CO2, with an average of \$183 per ton in the USA, although the programs provide other intended environmental benefits.	Economic assessment, life cycle analysis
Economic implementation and transaction costs too high. Including farmer-based research and planning, as well as associated farm-based investments in new equipment, infrastructure, labor, and management	More research effort focused on the cultural and policy complexities of soil carbon sequestration needed that matches the level of the effort that has been made on the technical issues.
Only approximately 2% of farmland is available for sale in a given year in the USA. We are unaware of any large-scale parcel-level studies evaluating whether farmland prices accurately reflect improvements in soil quality, and it is, thus, unclear whether conservation adaptation translates into higher property values.	

Technological / methodological	
Farming for carbon reduces productivity.	Farmers need to find disruptive technologies that will further improve soil condition and deliver increased soil carbon. (1) technology for soil, crop and forest management, (2) exploitation of underutilized land resources and existing biodiversity, (3) plant biotechnology, (4) microbial biotechnology, and (5) chemical technology.
Intensive practices such as drainage multiply causing emission of SOC.	Find best locations for productivity / sequestration trade-off
Many farmers practice rotational tillage and any carbon gains from reduced tillage could be lost during the ploughing phase	Knowledge exchange
Management changes might lead to increased N2O emissions which could counteract the carbon benefits	Research
Benefits would disappear with time as the carbon stocks reached a new equilibrium	Research
Farmers are already applying biosolids to soils so the benefits are not new	
Biosolids might only be available locally as the byproducts of specific industries	Investigate new forms of materials, e.g. paper waste
Reported gains in carbon might merely reflect its redistribution between different depths.	Research, recent meta-analysis suggests this is the case.
Whitmore et al. (2015) reviewed novel technologies that could be used to increase soil carbon storage. They concluded that some of these such as (i) the use of polyphenols to complex carbon or inhibit the enzymes that decompose it, (ii) the use of the methods of physical protection that operate in the subsoil in both the topsoil and subsoil and (iii) mineral carbonation all have potential for widespread application and reasonably rapid benefits. However, these technologies are not sufficiently developed for the potential benefits to	Technology development and verification of impact

be quantified. Any soil carbon sequestration that is achieved should be verified	
Poor technology translation. Researcher's sometimes have a poor understanding of their stakeholders and a lack of appreciation or acknowledgment about the complexity of policy implementation.	Knowledge Exchange
Geo-political	
Dependency on non-European countries for joint action that they don't contribute means global effort is minimal.	Work with international partners and stakeholders
Science	
The potential of C sequestration in deep soil still remains unknown.	Research
Cultivated areas offer opportunity, but the potential of additional sequestration in forests and grasslands remains more uncertain	Research
The 'Safeguarding our Soils' document acknowledges that further research is required to determine the best methods to boost soil carbon stocks.	Research to identify
Long-term experiments of SOC change due to management tend to be limited to productive arable soils.	Need long-term studies in non-agricultural soils (Arable 13% globally)
Need a holistic view of the fluxes of greenhouse gasses when estimating the benefits of agricultural interventions.	Research / meta-analysis
Soils reach their new equilibrium and no further carbon is sequestered.	Determine if there are nature based mechanisms that keep carbon being sequestered, e.g. peat growth, carbon in podzol subsoils. Even though rate might be slower.

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The EU introduced missions as a new instrument in Horizon Europe. Mission Boards were appointed to elaborate visions for the future in five Areas: Adaptation to Climate Change, Including Societal Transformation; Cancer; Healthy Oceans, Seas, and Coastal and Inland Waters; Climate-Neutral and Smart Cities; Soil Health and Food. Starting in autumn 2019, five Foresight on Demand projects supported them with foresight expertise and methodology.

This report provides the work in support of the Mission Board on Soil Health and Food. Adopting a long-term perspective, the project first contributed to better understand the drivers, trends and weak signals with the most significant potential to influence the future of soil health and food. With the Mission Board, three scenarios for 2040 were sketched. In the final step, system-thinking knowledge was applied to identify concepts, solutions, and practices able to promote systematic change in the sector.

Studies and reports

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