Soils for Europe

Basis for the implementation of an Operational Framework and minimum set of KPIs to monitor the Mission R&D activities

Deliverable D5.1

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1 Definition of scope

“Soils for Europe”, in particular the activities related to Work Package 5, aims at describing an operational framework based on measurable key performance indicators (KPI) that, together, provide a baseline for the assessment of the Research and Innovation (R&I) activities of the European Mission Soil. According to the European Commission research and innovation impact refers to a change or a benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, e.g. how R&I makes a demonstrable contribution to society and the economy.

There is on one side, the academic impact, which reflects what excellent research represents to academic advances across and within disciplines. And on the other, the societal and economic impact, meaning what excellent research brings to society and the economy, as a benefit to individuals, organisations and nations. Societal impact is about getting research and innovation put to use which, by its nature, is wide–ranging and complex. Assessment of R&I impacts is fundamental to enable researchers, research organisations, and research funders to evaluate the quality and performance of research, and to strengthen societal trust in the research and innovation system and in its outputs (EC 2021).

Specifically, in the context of this Deliverable, we will identify the main reporting mechanisms supporting the description of R&I KPIs and, at the same time, we will identify a minimum set of R&I KPIs that should be implemented and used to track the performance of the current and future Mission Soil R&I activities. Given the complexity and multiscale nature of R&I funding and activities (e.g., relying on both European and national funding), these R&I KPIs need to be adaptable not only to accurately describe the European reality, but also to collect information to depict the different regional conditions across Europe. Furthermore, we propose a framework for smart and comparable research impact narratives, which are not based on KPIs but on an impact journey along different phases. The narratives complement and enrich the information provided by KPIs.

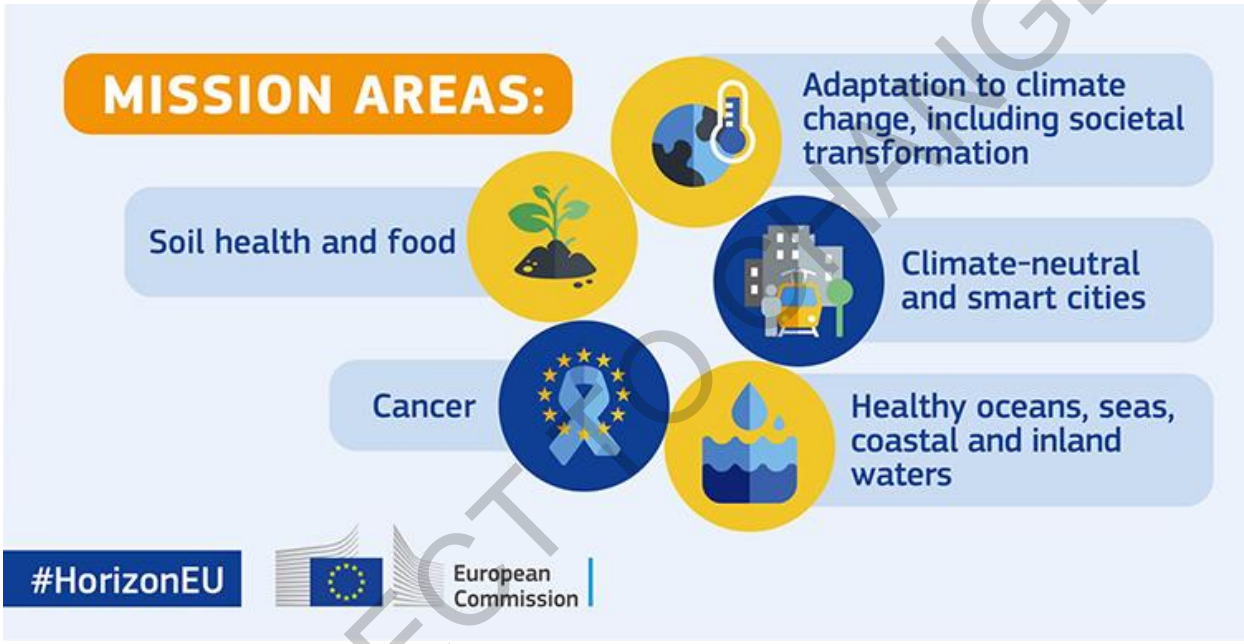
Achieving these goals requires the direct involvement of multiple European, national and international reporting mechanisms and the related institutions that currently participate in European reporting schemes. Engaging these institutions will allow to increase the feasibility of the proposed operational framework and increase the ownership by the European Commission (EC) of the mechanisms and KPIs proposed. While the final goal is to have all reporting mechanisms and related R&I KPIs well documented and internalised in reporting platforms that support the assessment of the Mission Soil, the current deliverable will focus on the description of the current State of the Art related to the assessment of R&I KPIs and on the initial proposal for a transdisciplinary approach to assess the European Mission Soil R&I activities and impact. As mentioned before, this includes the identification of a minimum set of complementary R&I KPIs that can support the Mission Soil Platform in the overall assessment of the Mission by being included in reasonable reporting mechanisms.

It is important to note that, currently, different projects funded within the Mission Soil programme are already focusing on KPIs for assessing the Mission goals, including the identification of edaphoclimatic and biological properties that can be tracked to assess the soil health

improvement of European soils. This also comprises KPIs that are adapted to different regional contexts, different land uses and different soil types. Here, we do not overlap with these assessments as we specifically focus on the assessment of the performance of R&I activities and their related impacts. In this context, “Soils for Europe” aims not only to address the R&I activities directly developed within the Mission Soil, but also as a consequence of it by expanding the scope of the KPIs to the potential cascade mechanisms deriving from the Mission Soil impact, i.e., the capacity of the Mission Soil to highlight soils and soil R&I activities as policy and decision-making priorities, placing them at the centre of political and social discussions within national and regional spheres all across Europe. Such scope will allow for a more targeted but inclusive approach to the assessment of the effective impact of the Mission Soil, monitoring not only the progress towards each of the specific Mission objectives, but also the trade-offs between these different objectives.

2 State of the Art of European reporting in the context of the Mission assessment

The five Missions of Horizon Europe 2021-2027 (Adaptation to Climate Change, which aims to support at least 150 European regions and communities to become climate resilient by 2030; Cancer, that will work with Europe's Beating Cancer Plan to improve the lives of more than 3 million people by 2030 through prevention, cure and solutions to live longer and better; Restore our Ocean and Waters by 2030; 100 Climate-Neutral and Smart Cities by 2030; and A Soil Deal for Europe, which aims to establish 100 living labs and lighthouses to lead the transition towards healthy soils by 2030) have been under some form of evaluation almost since their very start, as discussion on the continuation and development of the five Missions started already in 2021.



In 2023, a round of assessment is under way. According to the Horizon Europe legal basis (EU Regulation 2021/695, Art. 8.5), “an assessment of the first missions established under the Programme shall take place no later than 2023 and before any decision is taken on creating new missions, or on continuing, terminating or redirecting ongoing missions”. Art. 8.5 of the Regulation further provides that Missions should be assessed against the following criteria:

- an analysis of the Missions’ selection process;
- their governance;
- the budget (this is interpreted in terms of attracting funding from sources other than Horizon Europe, both public and private);
- the focus of the Missions; and
- their progress to date.

Additionally, a set of complementary criteria was introduced by the Project Group of Commissioners steering the assessment. These include the efficiency of the Missions, citizen involvement, added value, R&I content, institutional and public buy-in, Mission goals, and feasibility of the Missions' goals. Attention is paid in particular to the capacity of EU Missions to work in synergy with other instruments and policies, notably their capacity to link up with complementary funding sources and a maximisation of the impact of their outputs. As we write this Deliverable, this Assessment is not closed but is under way within the Commission and will be followed by an integration of targeted KPIs that will allow the continuous assessment of the Missions.

Therefore, the Mission Soil (together with the other Missions) will continuously need to be assessed in regard to its outreach, impact, outcomes, and the capacity to implement long-lasting changes that go beyond their temporal scope. This implies the description of indicators that not only address the mechanisms and funding directly provided by the Mission Soil itself, but also the cascade of mechanisms, funding schemes, regulations, and incentives created by Member States or regional bodies, that together contribute to the goals of the Mission. This makes the full assessment of the R&I activities of the Mission Soil complex, and should, for clarity and efficiency, consider several dimensions that extend beyond the traditional (e.g., number of peer-revied scientific publications and citation) measurements of success.

2.1 Overview of the Mission objectives and targets

The assessment of the Mission R&I impact needs necessarily to relate to its ambition and objectives. The Mission A Soil Deal for Europe is built on the acknowledgment that Europe needs healthy soils for healthy lives and a healthy environment – and thus soil should be on the top of our priorities when it comes to the efficiency of economic activities, resource management and adaptation and mitigation to climate change. The Soil Mission is at the core of Europe's twin green and digital transition and its quest to progress towards zero net emission, resource efficient, smart and circular systems of production and consumption. The Mission is also fully integrated into the wider "One-Health" planetary concept, connecting soil health with the health of ecosystems, food systems and people.

For the Mission, soil health is defined as "the continued capacity of soils to support ecosystem services". Maintaining and restoring soil health is a major and long-term endeavour, which requires transformative changes in practices by all sectors of society, across all types of land uses and scales in a joined-up manner. The evidence – mostly coming from the area of agriculture - illustrates that a range of practices exist that can significantly protect and improve soil health, particularly if their uptake was more widespread and applied over a larger scale. In the same vein, a recent study of the impact of the current CAP concluded that "the lack of technical knowledge and support appeared to be a key factor hindering the implementation of management practices addressing soil quality". The Mission needs to address this bottleneck.

Therefore, the Mission puts people at the centre of change. It is people and their actions who can drive a change for healthier soils. The Mission acknowledges the need to raise society's

awareness of the relevance of soils. And also, the need to deliver the necessary knowledge and innovations to enable broad action and support the transformative change in the management of soil, by all those land owners and managers who work with soil in their activity. This covers farmers, foresters, urban planners, scientists, business communities, politicians and citizens including the consumers, we all are. Changing awareness and behaviour is thus one of the dimensions that should be under focus in any assessment. This side of change, with awareness, knowledge, behaviour and practice, is particularly in focus in the assessment approach SOLO is setting up.

The Mission aims at moving by 2030 well beyond the current status of having only 30-40% of healthy soils in Europe. Therefore, the Mission has defined as overarching goal, that 100 living labs and lighthouses are set in place by 2030, to lead the transition towards healthy soils. Furthermore, the Mission describes a shared vision for Research and Innovation (R&I) and beyond to accelerate Europe's trajectory towards sustainable soil management and restoration as part of a wider, green transition in rural and urban areas. The goals of the Mission are substantiated with eight specific objectives that contribute to the achievement of existing EU policy targets related to: soil degradation, soil sealing, pollution and erosion, the protection and restoration of soil ecosystems and soil biodiversity and soil carbon sequestration and protection. The Mission also aims at reducing our global soil footprint.

They are specifically:

1. Reduce land degradation relating to desertification;

2. Conserve and increase soil organic carbon stocks;

3. No net soil sealing and increase the use of urban soils;

4. Reduce soil pollution and enhance restoration;

5. Prevent erosion;

6. Improve soil structure to enhance habitat quality for soil biota and crops;

7. Reduce the EU global footprint on soils;

8. Increase soil literacy in society across Member States.

For each of these specific objectives there are well defined targets, which were defined based on existing scientific evidence and data. Such targets need now to be tailored to the different regional contexts, land uses and soil types across EU. Projects financed within the Mission Programme are dealing with this downscaling and specification.

The Mission will be carried out through four operational areas, which correspond also to objectives:

- an ambitious cross-scale, inter and transdisciplinary R&I programme with a strong social science component to fill knowledge gaps and develop solutions for soil health and the

provision of ecosystems services. The mission addresses all types of land use in rural and urban areas, while traditionally, R&I and soil monitoring have focused on agricultural soils. Innovations in carbon farming, soil pollution (incl. pesticides) and restoration, soil biodiversity and the circular economy will be given special attention;

- an effective network of 100 living laboratories (LLs, for experimentation) and lighthouses (LHs, for demonstration of solutions) across rural and urban areas to accelerate the co-creation and uptake of solutions across farms, forest, natural landscapes and urban settings in a diversity of geographical and socio-economic contexts;
- a robust, harmonised EU framework for soil monitoring and reporting. This will serve as a basis to track progress towards major policy objectives and assess the effectiveness of measures for soil management;
- soil literacy, communication and citizen engagement, this representing a novelty of the mission's approach. Special attention will be given to digitisation, business involvement, the territorial dimension and global cooperation as cross-cutting themes of the mission.

The Mission will be rolled out in three, interconnected phases:

- The induction and pilot phase: to develop implementation structures, pool existing resources and bolster innovation capacity in Member States, regions and the sectors involved in the Mission (2021-2025);
- The expansion and innovation phase: to expand activities, generate and test innovations (2025-2030);
- The scaling up and mainstreaming phase: to scale-up solutions, adapt to local needs of a broader set of regions and mainstream good practices across sectors and territories (2027-2030).

The overlap between the various phases is due to the stepwise approach taken to build up the LLs: while some may still be scaling-up solutions, others may already be able to embark into mainstreaming good practices. Rigorous monitoring will assess progress and allow the planning to be adapted during the Mission's lifetime.

Through its operational objectives, and the resulting portfolio of activities, the Mission will provide pathways for re-designing production systems, change consumption patterns and transform the ways by which land and soils are managed. To trigger profound, systemic changes, Mission activities address both, soil health itself and the drivers of soil health such as land use practices, markets and value chains across agri-food systems, consumer behaviour, policies, regulation and education and advice. Special attention will be given to business involvement, digitisation as well as the territorial and the global dimensions as cross-cutting themes of the Mission.

2.2 Main mechanisms for reporting KPIs

Key Performance Indicators (KPIs) are measurable values that help to assess the progress and success of an organisation, process or specific activities within it. They are used to track performance and measure the achievement of predefined objectives. KPIs provide quantitative or qualitative metrics that reflect the critical factors for success and enable organisations to evaluate their performance effectively. When applied to the evaluation of policies, KPIs serve as benchmarks to measure the policy's effectiveness, efficiency, and impact. They help policymakers and stakeholders assess whether a policy is achieving its intended outcomes and whether adjustments or improvements are necessary.

Performance reporting is the tool used to generate data that can be used to assess and evaluate the implementation of the defined goals. It reflects the objectives and on the subjects of policies, policy instruments and activities, and their specific level of achievement. While reporting requirements should strike a balance between data collection (efficient, effective, timely) and administrative burden for the beneficiaries, they should ultimately allow to assess and evaluate the success of the implementation of policy goals. For that reason, it is important to recognise the context of reporting needs. EU policies and programs such as the Mission Soil, are developed to meet the main goals and objectives laid down in the Treaties and to fulfil international commitments, such as to meet the Sustainable Development Goals adopted by the United Nations in September 2015. Due to this, reporting may have double functions, on the one hand to provide information for evaluating EU policies' implementation, on the other hand to collect data to fulfil EU's reporting obligations. This double function means that the EU is not entirely free in setting the reporting mechanism, the KPIs and their sources, and should consider international standards. Some of EU's policy goals can be reached only on the bases of partnership programmes involving states outside of the EU (as in the PRIMA programme). In such a case the reporting (mechanism and sources) and the KPIs are characterised by co-development taking into consideration the partner states' abilities, possibilities, and interests. The double function of reporting can be recognised at project level as well. In that context, the Commission freely sets the rules of reporting along with the KPIs in the different kinds of funding instruments for the assessment and evaluation of the projects but also for getting the necessary data to assess, evaluate and improve EU policy implementation. This means, that reporting and KPIs always reflect on EU policy goals and objectives, and in the meantime the Commission always has to consider the context of reporting and its double function.

In general terms, once policy objectives are defined (assuming these objectives to be described as specific, measurable, achievable, relevant, and time-bound [SMART]), relevant KPIs can be identified. These KPIs should directly align with the policy goals and provide meaningful and measurable indicators of progress in order to:

- Establish baselines: *Baseline data is collected or established to serve as a starting point for comparison. This data is typically collected before the policy implementation to provide a reference for evaluating the policy's impact.*

- Monitor and measure: *Regular monitoring and measurement of the selected KPIs are conducted throughout the policy implementation period. This helps track progress, identify trends, and measure the policy's effectiveness in achieving its objectives.*

- Analyse and interpret: *The data collected through KPIs is analysed and interpreted to assess the policy's performance. This involves comparing the actual results against the*

predefined targets or benchmarks, identifying areas of success or areas requiring improvement, and understanding the factors influencing the outcomes.

- Adjust and propose improvements: *Based on the evaluation findings, policymakers can make informed decisions about the policy's future direction. If the KPIs indicate that the policy is not meeting its objectives, adjustments or improvements can be implemented to enhance its effectiveness.*

By using KPIs in policy evaluation, decision-makers gain insights into the policy's impact, identify areas for improvement, and make data-driven decisions for effective governance and policymaking. Importantly, the value and actual effect of policies can also be made transparent to citizens and relevant stakeholders.

In Europe, including within the Horizon Europe funding program, the reporting of KPIs is typically facilitated through multiple mechanisms and sources of data. European Regulation 2021/695, Art. 50 and 52 and Annex V provides for the rules of monitoring, reporting and evaluation of the Programme itself. Establishment of a publicly available database is required of which content includes an annual report on the progress of the Programme towards the achievement of the objectives based on time-bound indicators. Three main categories for impact pathways are set (scientific, societal and technological or economic) and proxy indicators are defined to track progress for short-, medium- and long-term. Both quantitative and qualitative methodologies are expected to be used for the compilation of these indicators. Funding bodies at all levels are required to make qualitative analysis to compliment quantitative data. For the midterm evaluation the assessment will be done with the assistance of independent experts. Relevant to the Mission Soil, these reporting mechanisms traditionally include:

- Reports on international commitments: *Parties to international agreements have an obligation to regularly report on their success in meeting the obligation committed. In general, the reports are made according to the specified reporting mechanism, KPIs, and sources of information, the use of official statistics or other public data is often required.*

- Reports on Partnership Programmes: *The success of partnership programmes is evaluated based on reports prepared by the partner states according to KPIs set for their activities, and reports related to the projects funded submitted by the beneficiaries referring to KPIs set in the tenders and funding agreements. Special attention is given to avoiding double audit or disproportionate administrative burden of documentation and reporting. This requirement has an impact on type and scope of the KPIs reported.*

- Funded Project Reports: *Recipients of Horizon funding are required to submit regular project reports that include information on project progress, achievements, and outcomes. These reports often include specific sections dedicated to reporting KPIs related to the project's objectives. In the context of the Mission Soil, and in particular of its Research and Innovation objectives, these types of KPIs may need further specification as they are often general and do not capture the multiple dimensions that need to be considered (see Section 3). Furthermore, Horizon-funded projects are expected to deliver specific outputs (often in the form of deliverables) and reach predetermined milestones. These*

deliverables and milestones serve as tangible indicators of progress and can be reported as KPIs. Nevertheless, these can also be further explored to obtain critical information about the content and metadata (e.g., number of researchers involved in the execution) related to these reporting items. Also, Horizon-funded projects are expected to demonstrate the potential impact and sustainability of their research and innovation outcomes. This requires the reporting of relevant KPIs that assess the project's contribution to economic, societal, and environmental dimensions. These include the description of the R&I performance of the project. Finally, the European Commission conducts regular audits and reviews of funded projects to ensure compliance and evaluate performance. These reviews may involve the assessment of reported KPIs to validate project achievements and outcomes. This is an important step to avoid a system solely based on self-reporting and ensure independence in the provision of relevant data.

- Horizon 2020 Online Reporting System: *Horizon 2020, the predecessor of Horizon Europe, had an online reporting system called the Participant Portal. This system provided a platform for project participants to submit periodic reports, including KPIs, as part of the grant management process. The information contained in this system as been partly migrated to the Horizon Europe portal but it can be further used to establish important baselines to assess the success of future policies, specifically in the context of R&I developments and KPIs. Given the specificity and scope of the Mission Soil goals, it is important to note that the identification and, more importantly, the generation of data in support of R&I KPIs should not be considered in a vacuum since, through the years and the multiple programs, the European Commission and the several projects and institutions funded through these programs have generated a substantial amount of information that can and should be used to assess the real impact of the Mission.*

- National progress reports: *Regulations may require to submit national reports on the progress of the implementation of EU's policy at national level including references to R&I activities and their success. This is particularly relevant for countries that are beneficiaries of structural funds. Beyond the mandatory information, often the structure, format, technical details and even the process for progress reports are set out by EU law. The mandatory information and technical details especially when they are part of templates may be considered as KPIs or contribute directly to them. Templates may also serve as guidelines for determining quantitative or qualitative KPIs.*

- Monitoring and Evaluation Frameworks: *The European Commission, which oversees the Horizon funding programs, establishes monitoring and evaluation frameworks to assess the performance and impact of funded projects. This includes Horizon Europe, the current framework program, that has its own monitoring and reporting system in place and is currently the main source of R&I indicators directly reported by the projects and the European Commission.*

It's important to note that the specific reporting requirements and mechanisms may vary depending on the type of funding instrument (e.g., grants, collaborative projects, individual

fellowships) and the specific call or program under which the funding is provided. Applicants and grant recipients typically receive detailed guidelines and templates for reporting KPIs as part of their grant agreements and project management procedures.

While data collection is essential and crucial for monitoring the implementation and the results of Horizon Europe, the general principle should be applied: efficient, effective and timely collection of data without increasing the administrative burden for the beneficiaries. The notion of integrated reporting may help the application of this principle. Based on the Commission implementing regulation on the structure, format, technical details and process for the integrated national energy and climate progress reports (2022/2299), the Commission is required to prefill the integrated progress report with data available from other existing reporting streams. This is an indication, that the standardization process of reporting has already begun, and/or same data are needed for the implementation of various policies, and the evaluation of their progress.

However, the application of this principle is challenging in reporting the R&I results of the Mission Soil due to its multi-level, multi-dimensional, transdisciplinary, trans-sectoral nature and with all the interrelations with other policies. The challenge is underlined by the fact, that there are several international and EU laws providing for obligations of member states on mandatory data collection and reporting as part of international commitments or of the EU harmonisation process reflecting on specific objectives, targets, or measure without alignment among them.

2.3 Current scope of the KPIs in the context of R&I activities

When evaluating research and innovation funding and policy strategies, Key Performance Indicators (KPIs) can be applied in several ways. These include evaluating the performance of the system that enables research and innovation at multiple levels, but also evaluating the impact that the research and innovation activities have on social, economic, cultural and/or environmental aspects. To this respect, current KPIs already allow to measure the success rate of researchers in securing funding through the implemented funding schemes, track the number of researchers trained, participation in workshops, acquisition of new skills, and career development opportunities provided through the available funding and policy strategies, and, to some extent, evaluate the ability of the current funding schemes to attract and retain high-quality researchers and innovative talent within Europe. These KPIs are mostly focussed on “Research Development” (here referred as enabling conditions) and try to assess the institutional ability to provide enough conditions to foster high quality research and innovation. Other aspects also relate to the measurement of research outputs, including the number of research publications (measuring the quantity and (eventually) quality of research produced), the number of patents and intellectual property (IP) registrations (focussing on the level of innovation and commercialization resulting from the funded research), and the number of collaborative projects, joint publications, and partnerships established through the funding mechanisms (highlighting the connectance of the research network that supports the scientific developments).

While these aspects are quite relevant to assess and steer the development of current and future research and innovation funding schemes, it is also important to assess how research is being

used by society and what impact (positive or negative) both research and the innovations that stem from it are having. This means there is a dimension of public and private take-up of research outputs, that needs to be considered.

In relation to the public take-up, ideally, scientific advice is independent of political or institutional interests, bring together evidence and insights from different disciplines and approaches, and ensure adequate transparency. High quality scientific advice, provided at the right time in the policy cycle, can improve the quality of legislation and therefore contribute directly to the better regulation agenda. In an optimal model, the policy cycle demands the scientific advice and the supply of such advice is efficient, effective, independent and transparent.

There are several KPIs that are already being measured by multiple European (and national) institutions including, the number of citations and scientific references to assess the influence of particular research on a given field (e.g., by tracking the number of citations and references received by peer-reviewed scientific publications from the funded projects), number of created start-ups or industry collaborations (to measure technology transfer and commercialization of practical applications), or to evaluate the influence of research and innovation policies on shaping public policy, industry practices, or addressing societal challenges. This last item related to measure the impact of research on shaping policy and practice is still open for debate and current KPIs and corresponding mechanisms still do not capture it in its full length. In fact, apart from more direct measures of both impact and outcomes, research and innovation KPIs are still far from capturing the real impact and benefits emerging from scientific contributions. New and probably more disruptive KPIs, or other assessment forms, are needed.

One important aspect to consider here is the fact that, in most cases, there is a lag between a specific innovation is produced and its impact on society. This may be a time lag - the time required for an innovation to be applied and produce results. It may also be a process lag - the lag between the innovation found in research and its applicability and resulting real world change. A good example of this is the recent evolution of Artificial Intelligence applications. While the introduction of tools like ChatGPT and the release of LAMMA by the Meta corporation (both in 2022) expanded dramatically the use of these tools by the general public and even fostered the rapid development of new optimizations, these developments were based on decades of prior research (e.g., the development of AlphaGO in 2016) and also were only possible because of a publication that dated from 2018 (REF) where the concept of “pre-training Transformers” was introduced by google AI research.

These developments in a high demanding and innovative industry can have profound changes in our society (e.g., the restructuring of several job descriptions) but even there the lag between critical developments and their social impact exists. Therefore, larger lags can be expected in field or industries that either have less profound (direct) social impacts or when the impact addresses other components of our social or environmental space (e.g., changes in policy and regulations or in institutional structures that support societal developments). In a recent study, van Klink (2020) showed a clear example of these soft changes and how impactful they can be. In his study, its shown increases in freshwater insect abundances at a rate of 11% by decade, contrary to decreases of terrestrial insect abundance (-9% per decade). These changes of insect

abundance are attributable to changes in policy that were focussed in having higher ecological quality standards for rivers and other freshwater systems. These changes in policy came after several decades of evidence on the ecological and socio-economic problems related to river pollution and even after policies were implemented, these also took decades to have the desired effect. Examples like this one percolate through literature (specially in life sciences) and show that measuring the impact of scientific developments may not be as trivial as monitoring a couple of quantitative KPIs. In this way, considering the policy take-up of research outcomes, at EU or national level, and through regulation or through incentives, is one of the components of societal impacts of research processes. The impact that such policies may have then on society corresponds to a next step, with a temporal gap in between the two which can be highly variable depending on the process.

KPIs that address the policy take-up can be developed - how research outcomes are reflected in regulations or incentive mechanisms. Measures within the CAP strategic plans and implementation at national or regional level is one example. Developing KPIs that can capture the temporal or other gaps between research and impact or that can track how research is used across society are quite hard to develop, at least in a quantitative way. Nevertheless, across European reporting schemes, there are several indirect KPIs that try to partially address some of these issues by assessing conditions for collaboration and internationalization and the economic and social benefits that directly come from the funded research and innovation projects. These include the number of international research collaborations facilitated through funded projects, the level/number of external direct investment or industry partnerships, the participation of researchers in other international research programs or projects, the number of jobs created or new businesses established, the level of industry adoption of research outcomes (e.g., by describing the number of new business models implemented or by the adoption of green approaches by specific industries), or improvement of environmental sustainability (e.g., by tracking the number of land managers that changed their production practices).

In the last decades, since the first funding programs, many advances were made in the ability of European institutions to capture the progress and the impact of the funded research and innovation initiatives. While this is the case, still aspects related to the economic growth, enhanced competitiveness and productivity, or social well-being are hard to pin to specific research developments. At the same time, the lack of an integrated system that collects information on both the national research and innovation funding and impact and the European initiatives, hinders the capacity to properly evaluate the short- and long-term impacts of such developments. A clear example of this, is the currently an inability to measure the magnitude of knowledge-based laws, regulations and decision-making both at European and MS levels. Also, in many cases, land managers react directly to changes in policy, but measuring how these changes in policy are driven by empirical knowledge and evidence, while possible, is not trivial and in recent assessments (REF) several relevant policies (e.g., the Common Agricultural Policy) showed extensive deficiencies. This result is a clear indication that such KPIs focussing on more extensive assessments of policy and management take-up are needed to properly assess the impacts of research and innovation in multiple sectors.

2.3.1 Main gaps in the current reporting mechanisms and KPIs

As mentioned before, while reporting research and innovation Key Performance Indicators has become more prevalent in European reporting, there are still important gaps and areas where improvement is critically needed. These include the need for standardization and consistency of multiple reporting mechanisms and KPIs, the assessment of the (qualitative and quantitative) long-term impact of research and innovation funding, the identification and integration in reporting mechanisms of interdisciplinary and cross-sectoral KPIs, clear KPIs that focus on open science and open innovation as a way to promote these practices across the EU, the need for specific KPIs on responsible research and innovation, knowledge transfer and uptake, and finally, changes in the current reporting mechanisms to improve data accessibility and the transparency of the assessments.

There is often a lack of standardisation and consistency in the reporting of KPIs across different funding mechanisms and levels of reporting (e.g., European, national). This makes it challenging to compare and benchmark the performance of research and innovation funding across the EU. Developing standardised frameworks and guidelines for reporting KPIs would improve comparability and enable more meaningful analysis, but this requires an agreement on the dimensions of success and how to measure and/or report the impacts (positive and negative) that derive from direct and indirect research and innovation funding. At the same time, while tracking the impact of public funding is of critical importance both for policymakers and for citizens, it is also important to measure the impact driven by private (e.g., industry driven) funding and how it percolates through society. An example of these impacts coming from industry can be exemplified but the agricultural machinery industry, where significant direct investments in research and optimization of mechanical harvesting have had profound impacts on how industrial farming is done at large scales and on the gains of performance by the food production industry, both social (e.g., by reducing employment) and economic (e.g., by increasing yields).

The previous examples are often hard to measure by traditional research and innovation KPIs that usually focus on quantitative short-term measures of impact and outcomes, such as publications or patents. However, capturing the often qualitative and long-term impact of research and innovation is equally important. Including indicators that assess the broader societal and economic impacts, such as policy changes, cultural shifts, sustainable employment or sustainable development, would provide a more comprehensive and accurate picture of the value created. At the same time, research and innovation are increasingly interdisciplinary and involve collaborations across multiple (sometimes previously disconnected) sectors. Unfortunately, existing KPIs may not adequately capture the complexities and synergies arising from such collaborations such as reflecting the existence of interdisciplinary research outputs, cross-sectoral partnerships, and interdisciplinary knowledge exchange. While these nuances are more difficult to evaluate, they also bring light to the most relevant paths that generate impactful research. In many cases, KPIs using this approach are already captured by European reporting mechanisms (e.g., the Responsible Research and Innovation portal or the European Innovation Scoreboard; even reporting some of these indicators at NUTS scale), part of the challenge here is to further discriminate the indicators calculated to reflect the specific influence of the European Missions, including the Mission Soil (e.g., the European Innovation Scoreboard reports on the “new

doctorate graduates" but no topical disaggregation is available hindering an assessment that allows to identify how many of these are related to topics relevant for the Mission Soil). Also, the Responsible Research and Innovation approach emphasises the ethical, social, and environmental dimensions of research and innovation such as open science, public engagement, gender equality, inclusion, and ethical considerations. Considering these aspects allows not only to assess the impact that research has on ecological processes and regulations, but also to measure the attitude of multiple actors towards research, technology and innovation which is particularly relevant for the Mission Soil as it involves stakeholders from land managers to policymakers. In particular, to adequately capture knowledge transfer and uptake by end-users, policymakers, or industry, and assess the dissemination, adoption, and utilization of research outcomes in real-world contexts, bridging the gap between research and practical applications.

Finally, it is important to note that in the last decades there was a continuous movement by European and national funding mechanisms to support the adoption of open science and innovation standards, including the adoption of open access option for published reports and peer reviewed science publications, but also for datasets derived from funded research and innovation projects. While these developments have implemented a significant change on how research is developed in Europe and by European researchers, traditional KPIs may not capture the extent of openness, such as effective data sharing and use, open access publications, or the existence and use of collaborative platforms. Recent publications (REF) have highlighted important drawback of current open access mechanisms even in scientific areas where open access is mandatory, like in the case of DNA sequencing where virtually all scientific journals require the underlying data to be made available in an open access repository. Nevertheless, despite this obligation, Jurburg et al. reviewed 26,927 publications in 17 microbiology journals and found that a substantial portion of the datasets (73%) placed in international open access repositories failed to meet the basic criteria of open access containing data which was not properly available or not reusable, or that contained faults in data formatting or data labelling, creating obstacles for data reuse. Capturing these types of nuances on the reported indicators, requires specific studies that have a deeper analysis on the content rather than on the quantity of the information being made available.

The development of standardised frameworks that combine multiple reporting sources (including specific consulting or in-depth studies) and an impact assessment deriving from multiple research and innovation dimensions is essential to develop comprehensive evaluations of the real-world impact of the research and innovation being funded (at multiple levels) in the context of the Mission Soil. This, combined with a strong focus on transparency of both reporting and indicators calculations and interpretations, would provide a more comprehensive understanding of the impact and value generated by these activities. At the same time, would improve the trust relationships between all relevant stakeholders, including the public, funders, researchers, policymakers, and evaluators.

3 A transdisciplinary approach to assess the European Soil Mission R&I impact

Transdisciplinarity is often presented as a new research approach to deal with societal complex problems so that research outcomes can directly link to practice and have a societal significant impact. It can be defined as different academic disciplines working jointly with practitioners to solve real-world problems. In more detail, transdisciplinary research can be defined as research that frames, analyses, and processes an issue such as: (1) the issue's complexity is grasped; (2) the diverse perspectives on the issue are taken into account; (3) abstract and case-specific knowledge are linked; and (4) descriptive, normative, and practical knowledge is produced and promotes what is perceived to be the common good. Representatives of different disciplines, of the private and the public sectors, and of the civil society, co-produce knowledge on an issue, trying to match (1) to (4). Furthermore, recognizing and accounting for context is a necessary precondition for designing and executing high-quality transdisciplinary research because of the multiple constraints and opportunities implicit within a context and its structure.

Research and innovation processes are undergoing major evolutions, partly due to the digitalisation of the research and discovery process (c.f., the diversity of research tasks and required skills has increased, the volume of previous findings and datasets is often staggering, and desired outputs are no longer restricted to scholarly publications), and the new knowledge sharing mechanisms, tools, and openness to contributions from other stakeholders in the system (open collaboration). Together, these have become essential to efficiently expand and measure the R&I impact, and there is a growing need of multi-, inter-, and trans-disciplinary approaches and collaboration to tackle ever more complex scientific questions and societal challenges in collaboration with societal stakeholders (EC 2021).

In the context of R&I impact assessment, working in transdisciplinarity helps avoiding misconceptions about the meaning of impact in research. Some of the most common misconceptions are: a) the limitation to academic outputs, which are easy to measure but do not fully capture the broader societal or practical outcomes and, as they are often less relevant for stakeholders outside of research, will not be directly influencing their reasoning; b) the belief that there is a linear relationship between research and impact along a predictable path, where research findings lead directly to specific outcomes, while the path is often complex and multifaceted (i.e., research findings may be interpreted differently by different stakeholders, the numerous contextual factors will more clearly be brought to the discussion); c) the expectation that researchers are solely responsible for achieving impact from their research (i.e., while researchers play a critical role in generating research findings, achieving impact often requires collaboration and engagement with end-users and other stakeholders, such as policymakers, practitioners, industry partners, and communities). Impact is often a collective effort that involves multiple actors working together to ensure that research findings are translated into meaningful outcomes. Therefore, by opening up to a community outside research, the debate on the assessment of the impact, it can be expected that a more complete assessment approach is defined.

Here, we propose a transdisciplinary approach to better target and contextualise the key dimensions of the assessment to be included, and for the design and selection of the related KPIs or other assessment approaches, like impact narratives. This transdisciplinary approach to the assessment of the research and innovation impacts includes not only the identification of KPIs but also the integration of narratives, based on the volume of research produced, that show how the research produced was/is able to influence the way how society works towards a better future. Using impact narratives together with KPIs also allows us to identify detrimental research and innovation pathways that should be adapted to better fit the desired purposes. Our argument is that unidimensional assessments will not capture the full breath of innovative pathways and, therefore, with hamper our ability to identify critical niches where Europe can spearhead research and innovation regarding the development of healthier soils. What can be seen as an extreme example (e.g., terraforming Mars and building the capacity for that, by exploring how soil microbes can support the development of fertile and sustainable soils in outer space) can lead to leading positions in the future research and development landscapes. These potential knowledge gaps can only emerge if a comprehensive analysis of the current needs and future needs is done and if the systems supporting their assessment can highlight emerging research and innovation topics.

This duality between KPIs and Impact narratives is at the core of our transdisciplinary approach as it provides a comprehensive way to address the multiple dimensions and research and innovation impacts deriving from the Mission Soil. While key performance indicators can include more quantitative aspects that allow to track the evolution of specific dimensions, impact narratives can be more descriptive and include more qualitative indicators. Nevertheless, it is important to refer that KPIs (and impact narratives) are not targets but rather a way to inform the path to the target previously defined. Therefore, before proposing specific KPIs or guidance on obtaining actionable impact narratives, it is important to define overarching goals, or expectations, for the performance of the Mission Soil (and related) research and innovation investments. While the goals for soil health are clear from the Mission Soil and the newly presented European soil Law/Directive, the same is not the case for the Mission's research and innovation goals.

In this context, we drive from the European Research Area policy agenda, the European Innovation Council, and the European open science policy to highlight the principles that underline the KPIs and the approach suggested here:

Enable Open Science: This aims to promote transparency, collaboration, and accessibility in research and innovation. Open Science involves sharing research data, publications, and methodologies openly and freely. By enabling Open Science practices, barriers to knowledge and information are reduced, fostering innovation, and allowing for increased reproducibility and impact of research outcomes.

Promote attractive research careers, talent circulation, and mobility: This focuses on attracting and retaining talented researchers within Europe by creating attractive career opportunities. It includes promoting mobility programs, career development support, and fair recognition of researchers' contributions. By nurturing a conducive environment for research careers, Europe aims to retain and attract top research talent, contributing to the advancement of

research and innovation. This also includes expanding the scope of disciplines to be targeted by the Mission Soil beyond soil sciences and ecology.

Promote gender equality and foster inclusiveness, including across European Regions: This addresses gender imbalances and promotes inclusivity in research and innovation. It involves promoting gender equality in research institutions, removing barriers to participation and career advancement for underrepresented groups, and ensuring equitable access to research funding and resources across European regions to minimize current regional imbalances.

Protect academic freedom in Europe: This emphasizes the importance of safeguarding academic freedom, ensuring that researchers can pursue their work independently, free from undue influence or restrictions. While we desire better science/knowledge-driven policies and legislation, it is important that the conclusions of researchers and innovative approaches are developed independently of immediate interest. Protecting academic freedom is essential for fostering critical thinking, creativity, and intellectual rigor in research and innovation.

Strengthen research infrastructures: This focuses on enhancing and developing research infrastructures across Europe. Research infrastructures encompass facilities, equipment, digital infrastructures, and resources necessary for conducting high-quality research. By strengthening research infrastructures, Europe and in particular the Mission Soil (e.g., in the context of Living Labs) can provide researchers with the necessary tools and capabilities to address complex scientific challenges effectively.

Promote international cooperation across the soil research and innovation community: This highlights the importance of fostering collaboration and cooperation among European and international soil research institutions, organizations, and networks. International cooperation enables knowledge exchange, joint research projects, and the sharing of resources and expertise, thereby enhancing the quality and impact of research and innovation. This is particularly relevant when considering partnerships between traditional research institutions (e.g., Universities) and non-traditional research partners (e.g., farmers organizations).

Empower Higher Education institutions: Empowering higher education institutions plays a leading role in research and innovation. It includes providing support for universities to develop strong research capacities, including research facilities and infrastructures, fostering partnerships between academia, industry (including technology, food production and distribution), NGOs and governmental organizations (e.g., regulatory bodies or agencies dedicated to the conservation of biodiversity), and promoting entrepreneurship and innovation within higher education institutions. This also includes supporting the development of long-term research strategies, fostering collaborative networks, and enhancing the institutions' ability to respond to societal challenges and emerging research priorities.

Bring science closer to citizens: This aims to increase public engagement and understanding of science and research. It involves promoting science communication, citizen science initiatives, educational outreach and training programs to bridge the gap between researchers and the public, including land owners and land managers. By fostering a better understanding of science and its societal relevance, citizens can actively participate in and benefit from research and

innovation activities. While it is expected that this type of knowledge transfer is done through the implementation of Living Labs, Lighthouses and in the context of the future soil districts, it is important to note that educational/training programs can substantially exceed these boundaries by being implemented in university syllabus and by percolating the teaching materials across all ages of formal education.

Build-up research and innovation ecosystems to improve excellence and competitiveness: This focuses on developing robust research and innovation ecosystems that support collaboration, entrepreneurship, and knowledge transfer across all types of stakeholders including academia, industry, government, NGOs, land managers, planners, among others. Innovation ecosystems can drive innovation, enhance excellence, and improve Europe's competitiveness in the global research landscape by creating more resilient communities that promote sustainable research environments.

Improve EU-wide access to excellence: We need to ensure equitable access to excellent research and innovation opportunities across all European regions and reduce disparities in the access, mobility and attractiveness of excellent researchers and innovators. This can be achieved by providing support, resources, and opportunities for research and innovation in regions with lower research capacities and promoting equal access to excellence, allowing Europe to tap into its full research potential regarding the goal of achieving healthy soils and maximize collective impact.

Support research and innovation investments and reform: This goal emphasizes the importance of adequate investments in research and innovation. It involves advocating for increased funding, efficient allocation of resources (e.g., like the current Mission Soil horizon projects), and implementing policy reforms (e.g., like the current soil health law) that foster a supportive environment for research and innovation. This support needs also to be flexible and permeable to new developments in research and new innovation pathways that may emerge in the future.

These policy goals collectively provide a framework to promote research and innovation across Europe, foster collaboration, address challenges, and create an environment conducive to scientific excellence, inclusivity, and competitiveness. Together, these will frame the identification of research and innovation KPIs for the Mission Soil and provide the basis for the evaluation and assessment of the Mission according to the SOLO perspective. Nevertheless, it is important to note that these principles would need further specification to be transformed into tangible goals with proper targets that can be tracked by the proposed KPIs. Without these measurable targets, tracking these principles will not return the desired outcomes.

3.1 Going beyond quantitative measures to the overall impact of the Mission Soil

A comprehensive assessment of the Mission Soil R&I activities and impact means to show strong evidence of what was changed due to the activities directly and indirectly related to the Mission (as the Mission Soil is expected to drive multiple activities across Member States and the industry). This implies not only considering the direct impact of the Mission Soil through the outcomes and impacts directly attributed to the funded projects (short/mid term perspective), but also the cascade of other finantial and boosting mechanisms related to the Mission objectives and launched by other entities besides the Commission, within and across Member States. Furthermore, the ambition is to identify and assess other changes which are linked to verified or expected improvements in the soil condition, which may result not from explicit initiatives or projects but from implicit changes in concerns, values, and management priorities by the public and private sectors (long term perspective). This implies a definition of impact that has both a regional and a temporal perspective, but that also expands the view on the multiple dimensions of impact that need to be considered.

To this respect, beyond direct funding and measuring the academic performance of the funded projects and research teams, it is needed to include the technological contributions and innovations associated to the developments in the Mission Soil, as well as the economic (e.g., development of new industries or business models), social (e.g., improvement of quality of life, changes in practices), and political impacts (e.g., passing of dedicated laws or the establishment of soils as an environmental priority). Beyond these dimensions of impact, it is also important to include aspects related to how research and innovation is contributing (directly or indirectly) to understanding of ideas and reality, values and beliefs, and the hierarchy of values by large groups of society, enhancing the environment and human health by tangible improvements in soil quality and health, or how changes in curricula or pedagogical tools may contribute to the improvement of qualifications and knowledge about soils. By considering all these dimensions, the Mission Soil, through the proposed KPIs and impact narratives, will be able to improve the assessment of its real impact on research, innovation and society.

To facilitate the interpretation of the KPIs proposed to monitor the research and innovation activities of the Mission Soil, we will then classify them according to the different dimensions that were described. Therefore, we included six dimensions: i) Academic; ii) Training and capacity building; iii) Public policy take-up and enabling conditions; iv) Market and practice take-up; v) Governance structures and institutional arrangements; and vi) Literacy and community building. These six dimensions require different types of knowledge (co-)production, which build upon and interact with each other. We use the systemic research framework developed in support of the soil mission implementation (Löbmann et al., 2022) to link R&I knowledge sources to these impact dimensions (Table 1).

Table 1 Linking research and innovation knowledge sources with the impact dimensions identified.

Impact dimension / Knowledge source	Academic	Training and capacity building	Public policy take-up and enabling conditions	Market and practice take-up	Governance structures and institutional arrangements	Literacy and community building
living labs & lighthouses	x	x	x	x	x	x
R&I for specific regions & sectors	x			x	x	
awareness, training, education	x	x				x
data managemen, sensing and monitoring	x		x			
assessment & modelling	x		x		x	
technical, economic, social innovation			x	x	x	
institutions & governance	x		x		x	
science based policy support	x		x			

To complement KPIs, for dimensions where those are not applicable, a narrative may be more informative. An impact narrative is a compelling statement that spells out a research and innovation contributions to knowledge, health, environment, economy, society or culture. These impact narratives refer to qualitative and contextual descriptions that help illustrate and explain the broader significance and societal value of research and innovation efforts. While KPIs primarily focus on quantitative measures to assess performance, impact narratives provide a qualitative counterpart by emphasizing the human, social, and transformative dimensions of the outcomes achieved. Therefore, a research and innovation impact narrative can be a powerful tool used to communicate the tangible outcomes and benefits of research to various stakeholders, including policymakers, funding agencies, and the public. It highlights how research has made a difference in the real world and can be used to demonstrate the value and significance of research findings.

Incorporating more qualitative indicators in the assessment of research and innovation impact can be quite beneficial as they allow for:

A more holistic evaluation of the outcomes: Qualitative indicators allow for a more holistic evaluation of research and innovation activities. They provide insights into the underlying context, processes, and dynamics that quantitative indicators alone may not capture. By considering qualitative aspects, such as stakeholder perceptions, user experiences, social dynamics, and cultural influences, a more complete assessment can be made.

Example 1: When measuring research and innovation activities in the field of healthcare, qualitative indicators can capture stakeholder perceptions and user experiences of new medical technologies. This information can provide insights into the acceptance and usability of the technologies, complementing quantitative data on their effectiveness and efficiency.
Example 2: In assessing the impact of a renewable energy research project, qualitative indicators can be used to understand the social dynamics and cultural influences within the community where the project is implemented. This information can help identify potential barriers or facilitators to adoption and inform strategies for effective dissemination and integration of the technology.

Contextual understanding: Qualitative indicators help in understanding the context-specific factors that influence the success or failure of research and innovation initiatives. They provide valuable information about the social, cultural, political, and economic conditions in which these activities are carried out. This contextual understanding can shed light on why certain outcomes are achieved and help identify necessary adjustments or improvements.

Example 1: When evaluating research and innovation initiatives in developing countries, qualitative indicators can provide valuable information about the social, political, and economic conditions that affect the success or failure of these activities. This contextual understanding can help identify specific challenges and opportunities unique to the local context and guide the design of tailored interventions.
Example 2: Qualitative indicators can contribute to understanding the contextual factors that influence the commercialization of research outcomes. By examining the cultural and market conditions, regulatory frameworks, and industry partnerships, policymakers and researchers can gain insights into the barriers and enablers of successful technology transfer and identify strategies to overcome challenges.

Stakeholder engagement: Qualitative indicators can facilitate stakeholder engagement and participation in the evaluation process. By incorporating subjective viewpoints, experiences, and narratives of stakeholders, such as researchers, innovators, industry representatives, and end-users, a more inclusive and diverse perspective is obtained. This engagement can lead to more informed decision-making and better alignment with the needs and expectations of stakeholders.

Example 1: When measuring research and innovation activities in the field of education, qualitative indicators can capture the perspectives of teachers, students, parents, and administrators. By incorporating their experiences and narratives, a more comprehensive assessment of the impact of educational interventions can be obtained, leading to more informed decision-making and improved alignment with the needs of stakeholders.

Example 2: In assessing the effectiveness of a government-funded innovation program, qualitative indicators can involve industry representatives and innovators in the evaluation process. By soliciting their subjective viewpoints and experiences, the evaluation can capture important insights into the program's strengths, weaknesses, and potential areas for improvement, fostering greater engagement and collaboration among stakeholders.

Estimate long-term Impacts: Research and innovation activities often have long-term effects that may not be immediately measurable or quantifiable. Qualitative indicators allow for the exploration of these long-term impacts, including changes in attitudes, behaviors, cultural norms, and societal dynamics. They provide insights into the transformative potential of research and innovation beyond the immediate quantitative outcomes.

Example 1: Qualitative indicators can explore the long-term societal impacts of research and innovation in the field of climate change. By examining changes in attitudes, behaviors, and cultural norms towards sustainability, qualitative data can provide a more nuanced understanding of the transformative potential of innovative technologies and practices beyond immediate quantitative outcomes.

Example 2: When evaluating the impact of a scientific research project, qualitative indicators can capture the long-term effects on scientific culture and collaboration. They can uncover how the project influenced interdisciplinary approaches, knowledge sharing, and the establishment of new research networks, providing insights into the broader scientific ecosystem and its evolution.

Identify unforeseen consequences: Qualitative indicators help identify unforeseen consequences, both positive and negative, that may arise from research and innovation activities. They allow for the exploration of unintended outcomes, serendipitous discoveries, or unintended consequences that may have important implications. By capturing these aspects, potential risks and opportunities can be better understood and managed.

Example 1: Qualitative indicators can uncover unexpected positive outcomes of research and innovation in the field of public health. By exploring the narratives of individuals affected by a new medical intervention, qualitative data can reveal serendipitous discoveries or unanticipated health benefits, contributing to a more comprehensive understanding of the intervention's impact.

Example 2: In assessing the consequences of a technological innovation in the transportation sector, qualitative indicators can help identify unintended negative impacts, such as environmental degradation or social inequalities. By capturing the perspectives of affected communities and stakeholders, qualitative data can inform mitigation strategies and responsible innovation practices to address potential risks and promote positive outcomes.

At the same time, an impact narrative, although also including quantitative KPIs, may be less precise but it is more integrative and encompassing than a series of KPIs, and therefore complementary to KPIs. By going beyond numbers and statistics, it helps tell the story of how research and innovation activities have made a difference in addressing societal challenges,

driving economic growth, improving well-being, and promoting sustainable development. These narratives help shed light on the connections and pathways through which research outcomes create meaningful change and contribute to broader societal goals. They provide a rich description of the outcomes and their implications, highlighting the relevance, significance, and practical implications of research and innovation activities. They also provide a narrative framework to capture the multifaceted impacts and the contextual nuances of policies, projects, and initiatives. Impact narratives often draw on case studies, success stories, personal testimonials, and real-world examples to illustrate the tangible benefits, transformative effects, and positive changes experienced by individuals, communities, and regions. Nevertheless, it's worth noting that impact narratives should be supported by robust evidence and data, drawing on both qualitative and quantitative sources. They should be carefully constructed to align with the specific policy objectives and context of the assessment, ensuring coherence and relevance. In addition, involving stakeholders in the development of impact narratives allows for diverse perspectives and a comprehensive representation of the impacts achieved.

For guidance, an impact narrative should include elements referring to:

Context: Provide a clear description of the societal challenge, problem, or opportunity that the research or innovation aims to address. In the case of the Mission Soil this challenge is tightly connected to the fulfilment of the Mission objectives and to the goals established in the recent EU initiatives/policies (e.g., Farm to Fork, Zero Emissions) and laws (e.g., the soil monitoring law and the nature restoration law). It is also needed to set the stage by outlining the relevant background information, policy context, or specific circumstances that make the research and innovation impact significant.

Stakeholders and Beneficiaries: Identify the individuals, communities, organizations, or sectors (going beyond soil sciences and including sectors from social sciences, anthropology, astrophysics, remote sensing, ecological modeling, education, etc.) that have directly benefited or been positively affected by the research and innovation activities that have been funded or supported. Highlight the specific beneficiaries involved and explain how they have experienced meaningful change or improvement as a result. One important note here, is that the identification of beneficiaries also should consider how they benefit through time and how these benefits may potentially change.

Outcomes and Results: Describe the specific outcomes, results, or achievements of the research and innovation that has been developed. These can include technological advancements, policy changes, improvements in processes or systems, new products or services, or advancements in knowledge. Clearly articulate the tangible and measurable results that have been achieved and link them to specific KPIs (e.g., number of peer-reviewed publications from funded projects).

Transformation and Change: Emphasize how the research or innovation has brought about transformative effects or positive change. Describe how the outcomes have influenced behaviors, practices, policies, or attitudes, leading to meaningful improvements in societal, economic, environmental, or other relevant dimensions. Here it is important to connect to elements like the participation of researchers (across various disciplines) in policy advisory boards or how

legislation is taking-up elements produced by researchers (e.g., in the six year review period of the soil law, identifying how much the current Horizon projects and related activities have contributed to enhance the way that soils are being evaluated would be a key impact to highlight).

Real-World Examples and Stories: Include compelling and relatable examples, case studies, or stories that illustrate the impact in practical terms. Personal testimonials, anecdotes, or narratives of how individuals or communities have been positively affected can bring the impact to life and make it more tangible and relatable. This can also be liked to the development of the Living Labs and Lighthouses and their respective communities of practice.

Quantitative and Qualitative Evidence: Support the narrative with robust evidence and data. This could include both quantitative metrics, such as the KPIs proposed, statistics, or economic figures, as well as qualitative information, such as interviews, surveys, or expert opinions. Showcasing a combination of quantitative and qualitative evidence strengthens the credibility and comprehensiveness of the impact narrative.

Broader Societal Significance: Connect the impact to broader societal goals, challenges, or priorities. Explicitly link these to current policies or public demand. Explain how the research and innovation being developed contributes to sustainable development, societal well-being, economic growth, policy objectives, or other relevant agendas. Demonstrate the relevance and alignment of the impact with larger societal aspirations.

Future Outlook: Provide insights into the potential future implications and opportunities resulting from the developed research and innovation. Highlight how the impact achieved can serve as a foundation for further progress, collaboration, or innovation in related fields or areas. Discuss potential pathways for sustaining and building upon the achieved impact, linking them to the policy goals established and how these evolved or were achieved.

Finally, it is important to present the impact narrative in a visually appealing and engaging manner. Visual and engaging presentations are vital in impact narratives as they effectively capture attention, enhance comprehension, and emphasize key points. In a world saturated with information, visual elements like graphics, images, and infographics immediately draw the audience's attention and simplify complex concepts. These visuals break down information into digestible formats, making it easier for stakeholders to understand and remember key insights. By strategically using visual cues, such as colour and placement, important messages within the impact narrative can be emphasized, creating a lasting impact. Moreover, visuals have the power to evoke emotions, foster an emotional connection, and increase stakeholder engagement. They facilitate accessibility by overcoming language barriers and catering to different learning styles, ensuring that the impact narrative is accessible to diverse audiences. Visual presentations, including dashboards, also support effective communication across stakeholders, transcending language and disciplinary boundaries. Still, it is important that the sources of information and reporting are credible and encompass the necessary elements and dimensions set for the assessment framework, these also need to consider regional biases in reporting and how different communities and cultures report and perceive the different indicators and narratives.

3.2 Making use of multiple reporting streams

As mentioned in Section 2.2, there are already several reporting mechanisms in use to assemble different types of indicators to assess multiple European goals. These reporting mechanisms already include: reports on international commitments; reports on Partnership Programmes; Deliverables and Milestones directly reported by the funded projects; the Horizon program online reporting system, including its monitoring and evaluation frameworks; impact assessment and sustainability plans; and project audits and reviews. Nevertheless, as mentioned before, given the specificity of the Mission Soil and of the stakeholders involved, many of these reporting mechanisms are not directly able to be subset to properly describe specifically the Mission Soil achievements. Also, there is a need to include information with finer spatial representation (e.g., Member State or regional levels) and information on less tangible impacts resulting from consulting or strategic studies (e.g., to assess the impact of research on legislation). Therefore, when assessing the impact of research and innovation for the Mission Soil we can identify **three overarching reporting streams** that should be integrated to provide a complete picture of the overall impact of research and innovation on soils and soil health across Europe. These include European reporting mechanisms (including direct reporting by projects), national reporting, and independent reporting mechanisms (including consultancies and automatic reporting streams) (Figure XY).

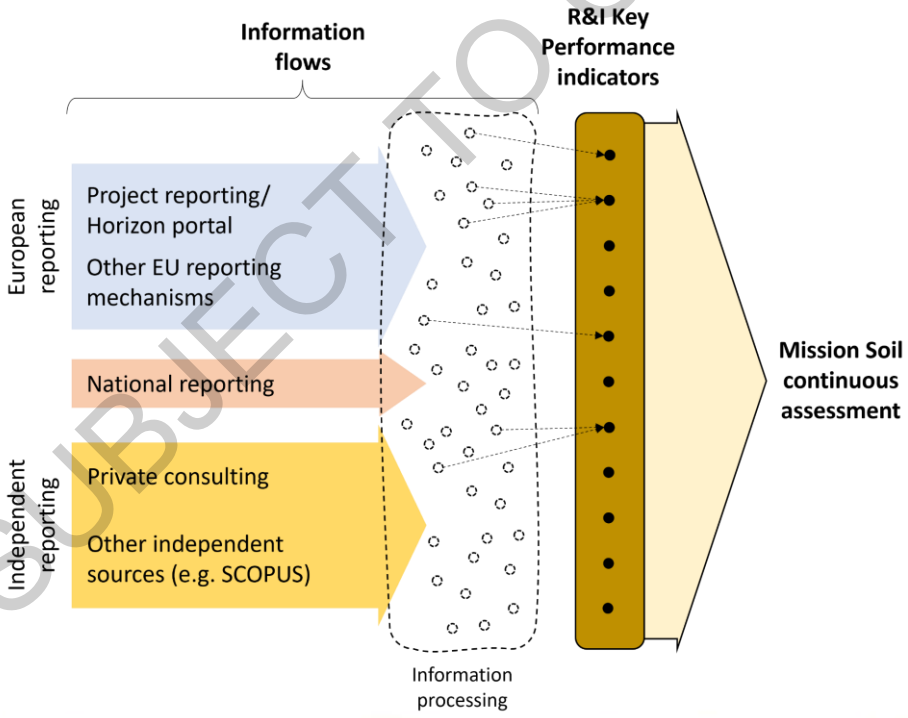


Figure XY How different information flows contribute to the development of key performance indicators to secure the Mission Soil continuous assessment.

Apart from project reporting and other elements present in the Horizon dashboard, European reporting should also include information coming from other European sources like the

Eurobarometer, Eurostat, among others. That said, it is important to mention that for many of these sources, although the raw data is spatially and even thematically desegregated, the information on specific indicators is presented in general ways without spatial or thematic specificity. For these, a higher degree of conversion of the data is required to meet the Mission Soil R&I impact assessment requirements. The same may apply to indicators that rely on national reporting mechanisms. For these, in many cases, surveys should be developed to improve the standardization of the data being reported. Furthermore, there are specific topics or KPIs for which reporting mechanisms do not exist or the information reported is too scattered and unstandardized. For these indicators and information other sources of information may be considered and the efforts to make the information useful might need to be accounted for.

In order to expand reporting mechanisms for research and innovation KPIs we need to consider additional sources of data and implementing diverse reporting channels. These may include:

- **Data integration and automation**: Leveraging technology and data integration can streamline the reporting process by connecting existing data sources, such as research publication databases (e.g., SCOPUS), patent repositories, or project management systems (e.g., the Horizon Portal), reporting can be automated to a certain extent. This would allow reducing the burden on researchers and organizations and mitigating the time spent on reporting for specific KPIs.

- **Surveys and questionnaires**: Surveys and questionnaires can be designed to collect data directly from researchers, project participants, stakeholders or organizations. These tools can capture both quantitative and qualitative information (including perceptions, key examples, best practices, or subjective assessments related to research and innovation) and target specific stakeholders, spatial resolutions (e.g., NUTS regions) or research and innovation dimensions that otherwise would not be able to be represented. If well crafted, these surveys can request information from MS funding agencies, land managers, law makers, among others, and can also represent different levels by for example including a direct link to the Living Labs and Lighthouses and their communities of practice. Surveys can be conducted periodically (e.g., like in the case of MS research and innovation funding agencies) or at the end of specific reporting cycles (e.g., like in the case of funded projects) to gather valuable insights.

- **Case studies and success stories**: In addition to quantitative KPIs, and although some of these can also be captured by implementing targeted surveys, including case studies and success stories can provide in-depth narratives and qualitative evidence of the impact and outcomes of research and innovation activities. These narratives can be collected through interviews, testimonials, dedicated reporting mechanisms (including surveys), or emerge from scientific publications where key examples are demonstrated.

- **Expert evaluation and peer review**: Current expert evaluation and peer review processes can be expanded not only to assess the quality and significance of the research and innovation outputs presented, but also to evaluate their overall impact. Including expert evaluations and peer assessments as part of the reporting mechanisms can provide valuable insights and additional data points. Therefore, when establishing or

requesting peer reviews of projects, outputs, and/or processes, reviewers should also be asked to provide an evaluation statement of the potential overall impact and suggest ways to either assess it or to further enhance it.

- **External data sources**: In addition to internal project data, leveraging external data sources can enrich reporting. This can include utilizing publicly available data, such as socioeconomic indicators, industry performance data, or innovation indices, to contextualize and benchmark the reported KPIs. This can also include the use of economic data related to the soil economy (e.g., agroforestry, food sector, nature restoration industry) or social data (through social media) to assess perceptions and interest. Here, as well as when using data collected from the Living Labs and Lighthouses, it is important to consider data protection clauses and the use of private information.

- **Stakeholder engagement and feedback**: Engaging stakeholders, including researchers, industry representatives, policymakers, and end-users, can provide valuable input and data for reporting KPIs but more importantly to produce viable and consubstantiated impact narratives. Collecting feedback, conducting focus groups, or organizing workshops can help capture diverse perspectives and ensure that results are relevant and aligned with the overall goals and needs.

Independently of the reporting mechanism selected, it is important to highlight that any assessment and particularly an assessment regarding the impact of research and innovation on European soils, should not only rely on self-reported data. For many of the sources of information previously identified, the data is generated by self-reporting (e.g., funded projects reporting) which may lead to a biased evaluation of the true impact of the Mission. To overcome this caveat, it is important that independent reporting or assessment mechanisms are also implemented to judge the real nature of the multidimensional impacts that research and innovation may have. Being them positive or unforeseen negative impacts.

3.3 Preliminary set of KPIs to assess the Mission Soil R&I activities

Complementarity between the scope of various Key Performance Indicators is crucial for a robust policy monitoring framework. It ensures a comprehensive assessment by covering different aspects of policy objectives and outcomes. This holistic approach provides a balanced evaluation that avoids bias and captures unintended consequences. Here, we used the classification scheme previously suggested to identify a comprehensive set of KPIs that covers the multiple dimensions of research and innovation. The selected KPIs broaden the evaluation, prevent a narrow focus, and enable policymakers to identify potential synergies or trade-offs. By considering multiple KPIs with complementary scopes, policymakers obtain a richer dataset for analysis and interpretation, which leads to a more nuanced understanding of policy effects. Additionally, it mitigates the risk of overreliance on single indicators and allows for adaptability to specific policy contexts. To ensure that all KPIs are reported adequately, we also identified multiple reporting streams that can be used to aggregate relevant information, as well as proposed different levels of spatial

disaggregation (from NUTS level 3 to EU level depending on the relevance) to allow for a better European perspective. The preliminary list of KPIs is listed below with a short description and a statement related to its importance or potential interpretation.

Table 1 Preliminary set of Mission Soil Research and Innovation Key Performance Indicators

KPI	Type	Class	Description	Importance	Level	How to measure
Integration of early-career researchers into project activities	Impact	Academic	Number of early-career (5 years after PhD) researchers integrated into project activities	Integrating early-career researchers into project activities fosters knowledge exchange, promotes innovation, and cultivates future research talent. This KPI will allow to track this integration.	EU	Horizon dashboard
MS introducing policy changes aiming to improve soil health	Impact	Enabling conditions	Number of MS introducing soil health-related legislation or specific regulations in their regulatory bodies.	Assessment of Mission Soil's impact on MS policies and regulations	MS	MS reporting Consulting
Proportion of non-permanent researchers in academic careers	Impact	Enabling conditions	Proportion of non-permanent researchers (at the time of funding) that stayed in academic institutions 10 years after the first project funding	Assessment of the impact over time of the Mission Soil in the career development of European young researchers	MS	Survey
Number of strategic partnerships established	Impact	Enabling conditions	Number of strategic partnerships formed during the course of funding by Mission Soil funded projects	This KPI measures the project's ability to establish strategic partnerships with relevant stakeholders in the soil health research and innovation domain. It can be measured by the number of partnerships formed during the project.	EU	Project reporting
Awareness of land managers with regard to soil health challenges	Impact	Literacy	Percentage of land managers aware of soil health challenges	Evaluate the contribution of R&I to the information outreach of the Mission Soil to land managers	NUTS level 3	Project reporting Survey Living Labs
Soil health awareness amongst European citizens	Impact	Literacy	Percentage of European citizens aware of soil health related issues discriminated in within country administrative regions	Evaluate the contribution of R&I to the information outreach of the Mission Soil to European citizens	NUTS level 2	Project reporting Survey
Amount of time needed to transfer research-innovation outputs into the market.	Impact	Market take-up	Amount of time (in months) that takes to adopt a specific innovation by the target audience, starting from the initial publication or concept to the launch of a marketable product or service.	Evaluation of the efficiency of the innovation process in the context of the Mission Soil	EU	Project reporting European Innovation Council
Innovation adoption rate by the target audience.	Impact	Market take-up	Number of innovation outputs that manage to reach and are being adopted	It helps to gauge the market acceptance and impact of the innovation produced by the project	EU	Project reporting European

KPI	Type	Class	Description	Importance	Level	How to measure
			by the target audience of the project.			Innovation Council
% of land managers having changed or adopted one or more of their practices in a direction improving soil health	Impact	Practice take-up	Number of land managers that changed farming practices towards soil health per total number of land managers	Assessment of the Mission Soil impact in agricultural practices, specifically identification of capacity building and knowledge transfer pathways from research to practice. These pathways can be direct (through direct knowledge transfer mechanisms) or indirect through legislation.	NUTS level 3	Project reporting Survey
Evidence-based legislation	Impact	Public take-up	Number of regulations or specific legislation on soil related topics (direct or indirect) with demonstrable use of scientific evidence	Assessment of the of Mission Soil's scientific outputs and outcomes introduction into policy making and legislation. The scientific evidence can come directly from Mission Soil funded projects, or from scientific initiatives that have gained from the Mission Soil activities.	MS	MS reporting Consulting
MS contribution to EU financed R&I projects related to the Mission Soil	Input	Enabling conditions	Euros invested (in percentage of GDP) by MS on European Mission Soil projects	Assess the level of MS co-investments on R&I related to the Mission Soil objectives	MS	Horizon dashboard LIFE reporting Biodiversa+
MS R&I funding related to the Mission Soil	Input	Enabling conditions	Euros invested (in percentage of GDP) by MS for national Mission Soil related projects	Assess the level of funding by MS to R&I national activities related to the Mission Soil objectives	MS	MS
Number of "new commers" in Mission Soil projects	Input	Enabling conditions	Number of currently funded researchers that haven't received European funding in the past 10 years	Evaluate the attraction and involvement of new participants in Mission Soil projects	EU	REA
Number of Mission Soil projects coordinated by partners from peripherical regions	Input	Enabling conditions	Number of Mission Soil projects coordinated by partners from peripherical regions as identified by the European Council of Regions	Assess the leading involvement of peripherical regions on Mission Soil projects	EU	Horizon dashboard
Number of partners from peripherical regions involved in the Mission Soil projects	Input	Enabling conditions	Number of partners from peripherical regions involved in the Mission Soil projects	To show the integration across European regions	EU	Horizon dashboard
Number of partners involved in the Mission Soil projects	Input	Enabling conditions	Number of partners involved in the Mission Soil projects	To show the dispersal of R&I funds	EU	Horizon dashboard
Number of research organizations involved in the	Input	Enabling conditions	Number of research organizations involved in the Mission Soil projects	Assess the involvement and funding of the academic-research sector on Soil Mission projects	NUTS level 3	Horizon dashboard

KPI	Type	Class	Description	Importance	Level	How to measure
Mission Soil projects						
Proportion of female researchers involved in Mission Soil projects	Input	Enabling conditions	Proportion of female researchers involved in Mission Soil projects relative to the total number of researchers involved.	Assess gender balance in Mission Soil R&I projects	MS	Horizon dashboard
Number of reviewers from peripherical regions involved in the project review process	Input	Governance structures	Number of reviewers from peripherical regions involved in the project review process	Assess the geographic equity in the distribution of scientific reviewer roles in the context of the Mission Soil	EU	REA
Number of stakeholders involved in Mission Soil projects per type	Input	Governance structures	Number of stakeholders involved in Mission Soil projects per type (e.g., researchers, farmers, land owners, industry, companies, NGOs)	Assess the multisectoral involvement of different partners in projects or activities related to the Mission Soil	NUTS level 3	Project reporting
Number of private companies involved in the Mission Soil projects	Input	Market take-up	Number of private companies involved in the Mission Soil projects	Assess the involvement and funding of the private sector on Soil Mission projects	NUTS level 3	Horizon dashboard
Number of NGOs involved in the Mission Soil projects	Input	Practice take-up	Number of NGOs involved in the Mission Soil projects	Measure the level of NGOs involvement in Soil Mission projects	NUTS level 3	Horizon dashboard
Field-Weighted Citation Index of peer-reviewed Publications resulting from the Mission Soil projects	Outcome	Academic	Number of peer-reviewed scientific publication in indexed journals attributable to the Member State by corresponding author	Measure the impact of Soil Mission projects in producing relevant scientific knowledge and its impact on the scientific community	NUTS level 2	Scopus
% of open-access research outputs resulting from the Mission Soil projects	Outcome	Academic	Number of open access publications, datasets or other scientific outputs openly available (at least CCBY) to be used in public repositories in comparison to the total number of scientific outputs developed by the Mission Soil projects	Assess the level of open R&I promoted by the Mission Soil	EU	Project reporting Horizon dashboard Google scholar
Ratio of research expenditures and outputs per project	Outcome	Academic	Evaluating the ratio of research output (such as publications, patents, or innovations) to the amount of funding invested in research activities	It helps to measure the efficiency of the research expenditure	EU	Horizon dashboard

KPI	Type	Class	Description	Importance	Level	How to measure
Number and share of upskilled researchers involved in Mission Soil projects with increased individual impact in their R&I field	Outcome	Capacity building	Number of researchers engaged with the Mission Soil R&I projects that by the end of funding, have completed an academic degree (Master, PhD, or post-graduation) and/or have increased their individual citation score.	Measure the level of excellence in Soil Mission projects in terms of expertise, improving the scientific community and developing academic careers	MS	MS reporting Horizon dashboard
Active soil monitoring systems	Outcome	Enabling conditions	Number of Soil Monitoring systems actively used	Assess the level of soil health monitoring capacity across Member States that can be used in support of soil health related R&I activities	MS	MS reporting
Number of soil health indicators included in soil monitoring systems	Outcome	Enabling conditions	Number of soil health indicators included in national soil monitoring systems	Assess the maturity and completeness of soil monitoring systems in support of R&I activities. Also it allows to assess how the Mission Soil R&I activities have influenced the development of such monitoring systems	MS	MS reporting EUSO
Percentage of Mission Soil funded projects which have citizen and end-users' engagement mechanisms in place after the end of project funding	Outcome	Literacy	Number of Mission Soil funded projects which have citizen and end-users' engagement mechanisms in place after the end of project funding in comparison with the total number of projects with such activities planned.	Assess the level of post-project continuity and societal/market impact. This is also important to evaluate the permanence of capacity building and public engagement activities with continuity beyond the Mission Soil	MS	Project reporting
Member States introducing a soil health certificate	Outcome	Market take-up	Number of MS with a soil health certificate	Assess the level of market integration of soil health requirements	MS	MS reporting
Number of businesses and companies developing or implementing science-based strategies for valorizing soils in their production and supply chains	Outcome	Market take-up	Number of businesses and companies developing or implementing science-based strategies for valorizing soils in their production and supply chains. Ideally, the specific scientific contributions should be track by survey.	Assess the capacity of Soil Mission outcomes in providing evidence-based instruments to be directly or indirectly used by the market in production and/or supply chain solutions	MS	MS reporting Survey
Number of patents and intellectual property rights (IPR) applications	Outcome	Market take-up	Number of innovations from awarded IPRs resulting from the projects funded by the Mission Soil project	Measure the applied impact of Soil Mission projects in market and society and to monitor the increase in the number of invention disclosures after the common IPR strategy is piloted.	EU	Project reporting
Number of research and innovation roadmap milestones achieved	Outcome	Practice take-up	Based on the Mission Soil R&I roadmap developed, number of milestones achieved	This KPI tracks the progress of the Mission Soil in achieving the milestones defined in the research and innovation roadmap.	EU	Project reporting Mission Secretariat

KPI	Type	Class	Description	Importance	Level	How to measure
Number of Mission Soil project researchers involved in national or regional advisory boards	Outcome	Public take-up	Number of Mission project researchers involved in national or regional advisory boards	Evaluate the influence, in terms of consultancy, of Soil Mission project members in regional decision making	MS	Project reporting MS reporting
Number of municipalities and regions pursuing citizen-identified R&I activities related to the Mission Soil	Outcome	Public take-up	Number of municipalities and regions pursuing citizen-identified R&I activities related to the Mission Soil objectives. These activities may include local soil monitoring programs, citizen driven environmental assessments or experiments, or other R&I activities.	Assess the impact of Soil Mission R&I activities on enabling authorities to act towards soil health at a local/regional level	NUTS level 3	MS reporting Reporting through the Council of Cities Living Labs
Co-creation of R&I outputs in Mission Soil projects	Output	Academic	Proportion of projects funded by the Mission Soil where European citizens and end-users contribute to the co-creation of R&I outputs	Assess the R&I capacity building potential developed by the Mission Soil projects	EU	Project reporting
Number of co-creation or capacity building events related to soil health	Output	Capacity building	Number of co-creation or capacity building events related to soil health (since September 2019)	Assess the R&I capacity building potential developed by the Mission Soil projects	NUTS level 3	MS reporting Project reporting
Number of Mission Soil Communities of practice created	Output	Capacity building	Number of Mission Soil Communities of practice created	Reflect the engagement of multiple sectors on the Mission soil objectives and R&I activities	MS	MS reporting ESP
Number of soil health related trainings	Output	Capacity building	Number of training sessions on soil health with a breakdown by stakeholder type as main target (e.g., researchers, farmers, land managers)	Assess the capacity of the Mission Soil R&I funded projects to transfer knowledge across sectors	NUTS level 2	Project reporting Living Labs
Number of experimental facilities, living labs and lighthouses created in the context of the Mission Soil	Output	Enabling conditions	Number of experimental facilities, living labs and lighthouses created in the context of the Mission Soil	Assess the capacity of MS to implement and maintain experimental facilities in support of R&I activities. Given the local expression of such activities, a sub-national level of representation is required.	NUTS level 2	Project reporting MS reporting Living Labs
Number of soil monitoring systems with open access policies implemented and accessible data	Output	Enabling conditions	Number of soil monitoring systems (out of the total number of national soil monitoring systems) with open access policies implemented and accessible data	Assess the capacity of researchers to access the data produced by soil health monitoring systems	EU	MS reporting EUSO

KPI	Type	Class	Description	Importance	Level	How to measure
Open access datasets related to soil health indicators from MS R&I projects	Output	Enabling conditions	Number of soil health indicators covered by accessible spatially explicit and quantitative open access datasets resulting from Member State R&I initiatives or projects related to the Mission Soil	Assess the capacity of researchers to access the data produced by soil health monitoring systems	MS	Survey
Number of soil health and sustainability educational materials developed in the context of Mission Soil projects	Output	Literacy	Number of educational materials including courses/modules in soil health education for primary and secondary schools, farmers and land managers, as well as for universities and the general public	Assess the capacity of European education institutions to integrate knowledge related to soil health in their curriculums and how this knowledge is being updated by using new research.	EU	Project reporting MS reporting Living Labs European Universities initiative European University Association

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