Ref. Ares(2023)8201463 - 30/11/2023

NBSOIL
Nature-Based Solutions for Soil Management

Analysing NBS categories through the IUCN Global Standard for NBS on soil health - initial version

Deliverable [D2.4]

20.10.2023

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs
Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Deliverable [D2.4]	[Global Standard for Soil NBS]
Related Work Package	WP2 – Soil and Nature Based Solutions
Deliverable lead	IUCN
Author(s)	Alberto Martín Sánchez (IUCN)
Contact	alberto.martin@iucn.org
Reviewer	Leszek Zukowski (CDR)
Grant Agreement Number	101091246
Instrument	Horizon Europe Framework Programme HORIZON-MISS-2021-SOIL-02
Start date	01 December 2022
Duration	48. months
Type of Delivery (R, DEM, DEC, Other)[1]	R
Dissemination Level (PU, CO, CI)[2]	PU
Date last update	20.10.2023
Website	nbsoil.eu

Revision no.	Date	Description	Author(s)
0.1	20.10.2023	First version	Alberto Martín Sánchez (IUCN)
0.2	27.10.2023	Second version	Alberto Martín Sánchez (IUCN)

Please cite this deliverable as:

Martín Sánchez A. Zukowski L., D2.4 Analysing NBS categories through the IUCN Global Standard for NBS on soil health. Initial version. NBSOIL project funded under grant agreement n. 101091246 of the European's Union Horizon Europe programme. May 2023. Document available at: nbsoil.eu

---

[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

List of tables

List of acronyms

BGI - Blue-green infrastructure

BR - Bioremediation

CAP - Common Agricultural Policy

CC - Cover crops

EAFRD - European Agricultural Fund for Rural Development

EC - European Commission

ERDF - European Regional Development Fund

ES - Ecosystem Service

EU - European Union

Fd - Forest diversification

FPIC - Free, Prior and Informed Consent

GIS - Geographic Information System

IUCN - International Union for the Conservation of Nature

LCA - Life Cycle Assessment

MS - Member State

NBS – Nature-based Solutions

OF - Organic fertilisers from locally available biowastes

P - Paludiculture

SDG - Sustainable Development Goals

SMART - Specific, Measurable, Attainable, Realistic y Time-bound

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Disclaimer

The opinions expressed in this document are that of the authors' and in no way reflect the opinion of the European Union or the European Research Executive Agency (REA). The European Commission is not responsible for any use that may be made of the information this document contains nor for any errors, as these remain the responsibility of the authors. This document is produced by Task Leader IUCN and is under Creative Commons license Attribution-Non-Commercial-Share Alike 4.0 International (CC BY-NC-SA 4.0), meaning that partners can share or adapt the content herein for free as long as recognition is rightly attributed to the authors, as such: Title of figure/diagram, Source: NBSOIL. Therefore, all content may be used by partners for their communication purposes, and moreover all partners are expected to read and deploy this communication strategy together.

The misuse or erroneous external use of the materials that may emanate from this deliverable, either purposely in adapting the content or unintentional as transmitting in another language, are not the responsibility of the authors who will remain available to support all NBSOIL partners throughout the duration of this project for the implementation of this communication plan. This document is designed and structured based on the principles and criteria outlined in the IUCN Nature-based Solutions (NBS) Standard. The IUCN NBS programme is not directly involved in the creation or endorsement of this analysis. This document is not an official IUCN tool, and any conclusions drawn from its application are the responsibility of the users. The content of this deliverable is the result of a theoretical process, and no context-specific documentation has been used to elaborate the analysis.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

1 Executive summary

This deliverable presents an initial analysis of Nature-based Solutions (NBS) categories considered in NBSOIL, including organic fertilizers from locally available biowastes, cover crops, paludiculture, forest diversification, bioremediation, and blue-green infrastructure in urban and peri-urban areas. The analysis aims to interpret existing documentation about each practice to provide information about the aspects considered in the IUCN Global Standard for NBS, identifying strengths and weaknesses associated with the indicators and criteria of the Standard through a bibliographic review and elaborating recommendations for better integration of these interventions within the NBS framework. The deliverable also discusses specific insights about the analysis process itself.

2 Expected impact

This deliverable, D2.4 Analysing NBS categories through the IUCN Global Standard for NBS on soil health - initial version, was developed during the first 12 months of the NBSOIL project. In this task, IUCN has conducted an initial analysis of the NBS categories, structured through the IUCN Global Standard for NBS (IUCN, 2020) to provide recommendations to better integrate these interventions within the NBS framework.

This analysis will serve as the foundation for the comprehensive analysis to be presented in D2.5 – Analysing NBS categories through the IUCN Global Standard for NBS on soil health - middle version and D2.6 – Analysing NBS categories through the IUCN Global Standard for NBS on soil health - final version. Additionally, it will form the basis for other activities within Work Packages (WP) 2 and WP3, including the development of capacity-building materials and technical recommendations for soil advisors. This initial analysis will be further developed in the upcoming versions of this deliverable, which will include the assessment of specific NBS according to the IUCN Global Standard for NBS.

3 Introduction

As the main result of T2.2 Using the NBS global standard for multicriteria assessment, D2.4 Global Standard for NBS includes the review of the NBS categories through the IUCN Global Standard for NBS (IUCN, 2020), providing recommendations to better integrate those interventions within the NBS framework.

D2.4 begins summarizing the objectives of the current document in Chapter 4 and outlining the context in which this document is elaborated, including an introduction to NBS in the aspect of soil health and a brief description of the IUCN Global Standard for NBS in Chapter 5.

The general remarks of the analysis are described in Chapter 6, which includes the methodology of the overall process and the limitations of the process. Chapter 7 includes conclusions and recommendations, including general guidelines to enhance the alignment between the analysed NBS categories and the IUCN Global

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Standard for NBS. Chapter 8 includes a summary of the results of the analysis and the scoring for each one of the NBS categories and finally, Chapter 9 details the rationale for each one of the indicators per NBS category.

4 Objectives

The objective of this document is to provide an initial analysis of the six NBS categories considered in NBSOIL: organic fertilisers from locally available biowastes, cover crops, paludiculture, forest diversification, bioremediation, and blue - green infrastructure in urban and periurban areas. The analysis follows the IUCN Global Standard for NBS (IUCN, 2020), its 8 criteria and 28 indicators, using information gathered from a bibliographic review. The insights gained from this review have been used to offer preliminary recommendations for better integration of these interventions within the NBS framework.

This report presents the results of an initial analysis with the following specific objectives:

1. Review the performance of soil-related NBS using the criteria and indicators outlined in the IUCN Global Standard for NBS.
2. Identify knowledge gaps and specific research and practice aspects that could be further investigated and explored for enhancing NBS interventions and their implementation process.
3. Mobilize and capitalize on existing knowledge and provide relevant sources for designing NBS solutions in alignment with the current state of scientific knowledge.
4. Extract lessons and insights to enhance the usability of the IUCN Global Standard for NBS.

5 Soil health and Nature-based Solutions

Nature-based Solutions is an umbrella concept that covers several approaches that have emerged from different fields, including Ecosystem-based Adaptation, Green Infrastructure, and Ecosystem-based Risk Reduction. Some of these approaches have emerged from the scientific research domain, while others from practice or policy contexts. However, they all share the objective of enhancing the beneficial features and processes of ecosystems to address societal challenges, such as food security, natural disasters, or climate change.

NbS are defined by IUCN as “actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits” (Cohen-Shacham et al., 2016).

The NBS concept has gained significant traction and was embraced, expanded, and supported by the European Commission, and has become increasingly common in literature on approaches for enhancing resilience to the effects of climate change. In recent years, NBS has been integrated into policy, funding priorities, scientific literature, plans, and strategies, and has been applied and implemented by numerous institutions.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

With the increasing recognition of NBS came a real demand of useful tools and guidelines to promote its implementation in several sectors and fields such as the soil health. In this sense, NBS are being considered as one of the main approaches that can improve soil health and increase the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health.

As NBS are increasingly being adopted, many interventions and soil management practices are being framed under the NBS concept, although they may not strictly follow specific principles and criteria. Additionally, with multiple definitions of NBS in use, there may be confusion about the concept, potentially hindering its development and uptake. In this regard, there is a lack of knowledge and practical experiences that explicitly relates NBS and soil health. To further strengthen the potential of the practices oriented to enhance soil health is crucial to deepen our understanding of how these practices are aligned with the specific criteria.

Recognising the lack of a common understanding and international consensus on NBS, IUCN has developed a Global Standard to mainstream the concept and to facilitate the verification, design and scaling-up of NBS. The IUCN Global Standard for NBS provides a clear definition and a set of principles to deepen our understanding of NBS, and guide research and implementation efforts with a systematic framework that facilitates the quality and credibility of these solutions, thus guaranteeing their effectiveness in providing benefits to both human well-being and biodiversity.

As NBS gains traction in policy, is adopted by multiple stakeholders and is used in a wide range of initiatives, there is an increasing need for greater clarity and precision regarding what the concept entails and what is required for its successful implementation. In this context, IUCN has facilitated the co-design of an NBS standard by combining knowledge, skills, and experiences from a wide range of stakeholders (IUCN, 2020b).

The IUCN Global Standard for NBS (IUCN, 2020), therefore, promotes a shared understanding and interpretation of the NBS concept, and facilitates the exchange of knowledge to enhance and improve applications, thereby increasing confidence in NBS among decision-makers. Furthermore, the IUCN Standard offers a specific and systematic framework to support the implementation of specific actions on the ground, accelerate policy development, and assess the design and execution of interventions through a process that promotes accountability. It also functions as a tool for developing a consistent approach to designing and validating concrete actions, avoiding a rigid framing with fixed, definitive thresholds for what NBS should achieve.

The IUCN Standard consists of eight criteria, each with a set of indicators, built on the NBS principles as well as feedback from a participatory process. These support users in two ways: 1) assessing the extent to which a proposed solution qualifies as an NBS, using a scale of strong, adequate, partial, or insufficient, and identifying what actions can be taken to further strengthen the intervention's robustness, and 2) facilitating the design of a solution that adheres to the criteria and indicators while building in adaptive management mechanisms to maintain the solution's impact.

- Criterion 1 emphasizes the importance of clearly identifying the societal challenge that the NBS will address to ensure deliberate and purposeful design aimed at meeting human well-being needs.
- Criterion 2 guides the design of an NBS by considering scale considerations. While intervention activities can be focused at the site scale, the robustness, applicability, and responsiveness of the solution should consider the interactions that occur across different social and ecological scales.

Co-funded by the European Union

UK Research and Innovation

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

- Criteria 3, 4 and 5 outline processes that can enhance the chances of positive outcomes for biodiversity, society and the economy. However, in order to achieve these three Criteria, trade-offs need to be determined and made, which are directly addressed in Criterion 6.
- Criterion 6 addresses the practicalities of navigating and balancing the trade-offs inherent in most natural resource management decision-making processes, including balancing immediate, short-term, and long-term outcomes. It emphasizes the importance of ensuring that trade-off decisions are made with equity, full transparency, disclosure, and consensus among all stakeholders impacted by the decisions.
- Criterion 7 promotes an adaptive management approach, where learning and action complement each other to evolve and improve the NBS solution. This approach enables NBS to address uncertainties and respond to unintended, unforeseen, and undesirable consequences of the intervention.
- Criterion 8 focuses on processes for mainstreaming NBS across spatial and temporal scales, to ensure that actions and impacts are sustained beyond stand-alone projects, sharing lessons to inform other solutions, and embedding the concept and actions into policy or regulatory frameworks. This includes linking NBS to national targets or international commitments.

Each of the criteria is articulated in several indicators that may serve as a tool to enable users to analyse the degree of alignment of their intervention with those eight Criteria and determine whether it adheres to the IUCN Standard for NBS.

6 General remarks

6.1 Methodology

The analysis of the NBS categories, which include organic fertilizers from locally available biowastes, cover crops, paludiculture, forest diversification, bioremediation, and blue-green infrastructure in urban and peri-urban areas, was conducted following the process described below.

First, an initial gathering of information and resources for means of verification was conducted by searching for each ‘NBS category name’ and ‘Nature-based Solution’ or ‘NBS’ as key words. This search was performed on bibliographic scientific databases, involving systematic searches for relevant articles, as well as the examination of grey literature and other research papers. Additionally, EU institutional official websites were utilized to review official communications, factsheets, and reports related to the practices. The bibliographic review was conducted in English language.

Secondly, an analysis of the NBS against the 28 indicators grouped under the 8 Criteria of the Standard was conducted. To accomplish this, the previously identified documents were reviewed to collect the necessary information for addressing the guiding questions included in the NBS Self-Assessment Tool for each indicator. When the information contained in the initial documents was insufficient, a secondary data collection process was initiated. This process involved two complementary steps. The snowball technique was utilized to identify additional publications by reviewing the reference lists and bibliographies of previously identified academic articles and furthermore, a search was conducted using the ‘NBS category name’ and specific keywords for each indicator to gather the needed information.

Once all the gathered evidence was structured according to the IUCN Global Standard for NBS, a score was assigned to determine whether the reviewed documentation provided strong or weak evidence regarding how

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government’s Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

the NBS categories addressed each indicator. The scoring criteria were established according to the scaling outlined in Table 1. In cases where the evidence found was insufficient, the rating for that particular indicator was defined as N/A. A brief explanation describing the reasoning behind the rating chosen for each indicator was included in Chapter 9.

Table 1. Scores given for each of the indicators in the analysis. Source: original work based on IUCN, (2020b)

How well has the indicator been meet according to the documentation?	Score
Very strong	3
Strong	2
Weak	1
Very weak	0
Insufficient evidence	N/A

In addition to the necessary information for addressing the guiding questions, the analysis also considered other findings. This encompassed the following:

- The most relevant aspects of each solution, along with the identification of potential gaps and opportunities for improvement. Additionally, key messages and lessons learned were extracted to provide recommendations that promote alignment of the practices with the Standard.
- Key issues to enhance applicability of the analysis process itself, including the identification of the criteria and indicators that are more challenging to address and comply with.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

6.2 Limitations of the analysis

During the analysis several challenges arised. The challenges that have arised are related with the difficulty to identify the existence and quality of specific processes and the consideration of concepts that are not explicitly integrated into the NBS categories.

There are several processes that NBS actions must integrate to meet the Standard criteria. These processes encompass NBS design, documentation, stakeholder participation, monitoring, risk management, communication, target reporting, and economic analysis. While these activities may be integrated for specific strategic interventions, they are not typically recognized at an operational level. This poses a challenge, even for the most mature projects, as they are highly time-consuming and resource-intensive, demanding extensive knowledge. In this regard, monitoring and documentation processes are crucial in a strategic, top-down approach, providing relevant information for administration and policymaking at regional, national, and global institutional scales, but they are often distant from day-to-day management. On the other hand, the Standard considers that decision-making processes, human well-being outcomes, stakeholders, trade-offs, risks, and societal challenges have to be identified, documented, and periodically reviewed. Nevertheless, there is a history of traditional interventions that managed nature in ways that provided benefits for society and biodiversity without formal monitoring and documentation processes.

The Standard encompasses several concepts, such as trade-offs, unintended and adverse consequences, risks, corrective actions, safeguards and adaptive management. These concepts have not been explicitly integrated into many disciplines and management systems and some are relatively new, especially at operational level.

These limitations may be considered as an opportunity to encourage the systematic integration of specific concepts and processes across various disciplines and management systems, potentially leading to enhancements in the implementation of NBS. However, in certain contexts, such as agriculture, they may also be perceived as challenges.

Additionally, some of the NBS categories that were analysed, such as organic fertilization from locally available biowastes and cover crops, are practices that can be found integrated into broader management systems like agroecology, permaculture, or biodynamic agriculture. Other NBS categories, such as forest diversification or bioremediation, are more comprehensive systems that include various practices and cover a wide range of interventions with diverse characteristics and impacts. Analysing general management systems based on a bibliographic review presents a challenge since the level of alignment with different indicators is context-specific and depends on how actual practices are implemented and designed at the local level. On the other hand, the level of alignment of a specific practice, such as cover crops, with some of the Standard's indicators will depend on the broader management system in which the practice is integrated. It could be considered that some indicators of the Standard have a perspective that is too strategic for analysing operational practices, and others are too context-specific for analysing management systems or approaches.

In this regard, it should be highlighted that organic fertilisation is not compatible with the NBS definition, as it is not an "action to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits".

Finally, the lack of a public scientific consensus on some specific issues considered in the Standard for each of the NBS categories, as well as the dispersion of information sources is a relevant limitation of the current analysis.

Co-funded by the European Union

UK Research and Innovation

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

7 Conclusions and recommendations

Maximum ambition should always be the target when discussing how interventions adhere to the NBS Standard. However, it should also be kept in mind that achieving a perfect rating for each criterion may be challenging and not entirely realistic. Additionally, it should be considered that there is a lack of information and documentation for adequately assessing certain indicators, especially within some of the NBS categories under consideration.

There is no NBS categories that fully adheres to the IUCN Global Standard for NBS. However, Blue-green infrastructure (BGI), bioremediation (Br), and paludiculture (P) have higher adherence to the Standard. In general terms, Inclusive governance (Criteria 5) and Balance Trade-offs (Criteria 6) show lower performance, while Design at Scale (Criteria 2) and Biodiversity Net Gain (Criteria 3) achieve the highest ratings.

Every analysed NBS category, with the exception of BGI, could be more directly oriented to address clearly specified challenges that have significant and demonstrable impacts on society. This should be prioritized through a transparent and inclusive consultation process involving the right holders and beneficiaries. Stakeholder mapping, engagement planning, and social impact assessment are valuable tools to align these interventions with this specific objective. While the societal challenges addressed by all NBS align with widely accepted narratives, it is crucial to analyse and document the drivers of and responses to identified challenges, especially those relevant at a local context, such as climate change adaptation or disaster risk reduction. To achieve Specific, Measurable, Attainable, Realistic, and Time-bound (SMART) human well-being outcomes, benchmarks relevant to the considered societal challenges and the national/local context, should be identified and assessed. Gathering information and evidence about these specific human well-being outcomes is particularly relevant for aligning Organic fertilisers from locally available biowastes (OF) and Cover Crops (CC) with the NBS Standard.

Most NBS categories, with the exception of Br, consider at least partially the interactions between the economy, society, and ecosystems. However, the consideration of these interactions in the decision-making process throughout the intervention timescale should be more detailed, both within and surrounding the intervention area and it is essential to consider potential knock-on impacts on and from other areas and sectors. Br, in particular, requires a 'systems' framing to recognize and respond to the interactions between the economy, society, and ecosystems, integrating them into the decision-making process. While the design of BGI is adequately integrated with other complementary interventions and seeks synergies across sectors, further investigation into synergies across sectors is recommended to incorporate the most relevant complementary interventions within the design of the other NBS categories. Geospatial analysis, multicriteria spatial analysis, and landscape-level assessment would be useful tools in this regard. All NBS categories partially or adequately integrate risk management. However, a systematic risk analysis should be implemented to identify drivers and integrate mitigation measures into the design of the NBS.

Ecosystem assessment, species assessment, biodiversity baseline assessment, and environmental impact assessment are methodologies that could be valuable in ensuring that NBS categories respond to evidence-based assessments of the current state of the ecosystem and the prevailing drivers of degradation and loss. This is particularly relevant for OF and CC interventions. In this context, the IUCN Land Health Monitoring Framework provides a list of tools to assess biodiversity at different levels, along with complementary indicators to assess biotic structure based on available or newly collected direct data. It is also crucial to identify

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

and monitor possible adverse impacts of NBS interventions on ecosystems, ecological processes, and species, especially in Forest diversification (Fd) interventions.

To enhance the economic viability of P and BGI, which are the NBS categories with lower ratings in these criteria, the use of cost-benefit analysis, natural capital accounting approaches, and benchmark analysis at market and financial levels would be particularly relevant. Specifically, conducting cost-effectiveness studies, analysing sensitivity against critical variables (including changes to key regulatory and subsidy arrangements), and assessing the long-term economic and financial sustainability, as well as economic risks, would strengthen the economic performance of the NBS.

Considering the case of paludiculture, one of the primary challenges lies in its inherently extensive and low-profit nature. In instances where there is a push, whether through encouragement or legal mandates, for farmers to sustain this system, it becomes critical to furnish them with alternative sources of income. Two viable approaches exist to ensure the economic viability of farmers engaged in paludiculture habitats characterized by limited profitability. Firstly, the promotion of profitable wetland management methods involving advocating for economically viable methods of wetland management. Examples include cultivating reeds for roofing materials, engaging in animal production with the generation of high-value products such as cheese with geographical indications, among other lucrative practices. Secondly, the compensation for lost income through subsidies and agri-environmental programs through subsidies and participation in agri-environmental programs. Notable examples include Natura 2000 areas linked to various agri-environmental and climate payments and alternative incomes for farmers. For wetland owners and farmers, engaging in agricultural activities or cultivation within wetlands often proves financially unsatisfactory, leading to the unintended consequence of soil drying. To address this issue, a strategic reduction in soil drainage becomes imperative, aiming to strike a balance between increasing production profitability and preserving paludiculture resources. Bridging the income gap for farmers is essential, and mechanisms to cover or reduce this gap must be explored and implemented to ensure the economic sustainability of paludiculture initiatives. In this regard, generating alternative and supplementary incomes and compensation mechanisms in the context of maintaining and protecting soil health and the provision of environmental services could be crucial for farmers. Also, guarantee the access to the most cost-effective agricultural good practices that can be carried out in wetlands and stablishing links to new employment opportunities such as touristic and educational activities could facilitate the economic viability of paludiculture.

All NBS categories receive relatively low ratings for governance criteria, and there is a significant lack of information regarding how participative processes are integrated into interventions. Enhancing the integration of feedback and grievance resolution mechanisms, clearly defining participative activities, incorporating stakeholder analysis and engagement activities, and documenting and sharing key decision-making processes would ensure greater alignment of NBS with the Standard. Notably, BGI has the better rating in the governance criteria.

The balance of trade-offs could be enriched by a deeper acknowledgment and respect for the rights, usage, and access to land and resources, along with the responsibilities of different stakeholders in P, BR, and Fd. The development of safeguards and the definition of mutually agreed-upon trade-off limits, as well as how trigger responses could be implemented, would be useful for CC and Fd actions. Additionally, the complex set of costs, benefits, and co-benefits involved in BGI interventions should be further analysed.

The development of an NBS strategy, which includes the rationale behind the intervention, a precise articulation of the intended outcomes, and a clear understanding of how these outcomes should be achieved through the actions taken, will reinforce the adaptive management of all analysed NBS categories. A

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

monitoring and evaluation plan would be especially relevant for OF, Fd, and BGI actions, and a learning framework with iterative learning that enables adaptive management is crucial for OF and CC.

Finally, communication strategies and specific measures to systematically capture and share lessons should be considered as part of the interventions, especially for OF, CC and Fd. It is very important to raise farmers' awareness of the importance of wetlands in the context of providing environmental services.

8 Results of the analysis

Chapter 8 includes the results of analysing the six NBS categories considered in NBSOIL following the structure of the 28 indicators and 8 criteria of the IUCN Global Standard for NBS. The scores have been assigned according to the legend included in Table 3.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Table 2. Scores assigned to each NBS category based on the reviewed documentation. Scores are defined to answer how well the indicator has been met according to the reviewed documentation. Very strong: 3, strong: 2, weak: 1, very weak: 0, insufficient evidence: N/A.

Criterion	Indicator	OF	CC	P	BR	Fd	BGI
Criterion 1: NBS effectively address societal challenges	1.1 The most pressing societal challenge(s) for rights-holders and beneficiaries are prioritised	1	1	1	1	1	2
	1.2 The societal challenge(s) addressed are clearly understood and documented	1	1	2	1	1	1
	1.3 Human well-being outcomes arising from the NBS are identified, benchmarked and periodically assessed	N/A	N/A	2	2	1	2
Criterion 2: Design of NBS is informed by scale	2.1 The design of the NBS recognises and responds to interactions between the economy, society and ecosystems	2	1	2	N/A	1	2
	2.2 The design of the NBS is integrated with other complementary interventions and seeks synergies across sectors	1	1	1	1	1	2
	2.3 The design of the NBS incorporates risk identification and risk management beyond the intervention site	1	1	1	2	1	1
Criterion 3: NBS result in a net gain to biodiversity and ecosystem integrity	3.1 The NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss	N/A	N/A	2	2	1	2
	3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed	1	1	2	1	2	1
	3.3 Monitoring includes periodic assessments of unintended adverse consequences on nature arising from the NBS	1	1	1	1	N/A	1
	3.4 Opportunities to enhance ecosystem integrity and connectivity are identified and incorporated into the NBS strategy	N/A	N/A	2	1	2	3
Criterion 4: NBS are economically viable	4.1 The direct and indirect benefits and costs associated with the NBS, who pays and who benefits, are identified and documented	1	2	0	1	1	0
	4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies	1	1	0	1	1	N/A
	4.3 The effectiveness of the NBS design is justified against available alternative solutions, taking into account any associated externalities	2	1	0	2	2	2
	4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance	2	1	1	1	1	N/A
Criterion 5: NBS are based on	5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all	N/A	N/A	N/A	N/A	N/A	N/A

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

inclusive, transparent and empowering governance processes	stakeholders before an NBS intervention is initiated						
	5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free, Prior and Informed Consent (FPIC)	N/A	N/A	1	0	N/A	1
	5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention	0	N/A	1	N/A	N/A	1
	5.4 Decision-making processes document and respond to the rights and interests of all participating and affected stakeholders	N/A	N/A	N/A	N/A	N/A	N/A
	5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decisionmaking of the stakeholders in the affected jurisdictions	N/A	N/A	N/A	N/A	N/A	2
Criterion 6: NBS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits	6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions	1	1	1	2	1	N/A
	6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders, are acknowledged and respected	1	1	N/A	N/A	N/A	1
	6.3 The established safeguards are periodically reviewed to ensure that mutually-agreed trade-off limits are respected and do not destabilise the entire NBS	1	0	1	2	N/A	1
Criterion 7: NBS are managed adaptively, based on evidence	7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention	1	1	1	2	1	1
	7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle	1	2	2	2	1	1
	7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle	0	N/A	1	1	1	1
Criterion 8: NBS are sustainable and mainstreamed within an appropriate jurisdictional context	8.1 The NBS design, implementation and lessons learnt are shared to trigger transformative change	0	0	1	1	N/A	1
	8.2 The NBS informs and enhances facilitating policy and regulation frameworks to support its uptake and mainstreaming	1	2	2	2	1	1
	8.3 Where relevant, the NBS contributes to national and global targets for human well-being, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)	1	2	1	1	1	1
Criterion	**Indicator**	**OF**	**CC**	**P**	**BR**	**Fd**	**BGI**

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

9 Analysis of the NBS

The analysis included in Chapter 9 details the rationale for each one of the indicators per NBS category and provides information about the aspects considered in the IUCN Global Standard for NBS, identifying strengths and weaknesses associated with the indicators and criteria of the Standard through a bibliographic review.

9.1 Organic fertilisers from locally available biowastes

Organic fertilizers consist of plant or animal-based materials that result from byproducts or end products of naturally occurring processes, such as animal manure and composted organic matter. In the NBSOIL Project we consider organic fertilisers that produced from locally available biowastes and distributed based on proximity criteria. Organic fertilising comes with several benefits in soil health, plant growth and productivity and prevent the emission of CO2 from fossil fuel-derived fertilisers.

Criterion 1: NBS effectively address societal challenges

1.1 The most pressing societal challenges for rights holders and beneficiaries are prioritised

OF using locally available biowastes has shown its potential to address several societal challenges, including biodiversity loss, land degradation, climate change mitigation, and food security, ensuring yields that guarantee a sufficient and adequate food supply (Sharma et al., 2019).

In their study, Sharma et al., (2019) identified multiple benefits arising from recycling organic waste as a fertilizer in agricultural fields. These benefits encompass improvements in soil health and nutrient characteristics, soil structure, and a reduction in erosion, along with an increase in soil organic matter. They also observed enhanced plant growth and productivity, as well as a contribution to climate change mitigation through reduced greenhouse gas emissions. Furthermore, recycling organic waste helped conserve land resources by decreasing the amount of waste sent to landfills, reducing waste volume at dumpsites, and minimizing environmental pollution. Lastly, this practice also entails a reduction in the risks associated with over-fertilization and contamination.

While organic fertilization can offer a solution for improving soil health and managing organic waste while minimizing environmental degradation (Sharma et al., 2019), several critical aspects exhibit a high degree of uncertainty. This uncertainty primarily pertains to environmental performance, but also encompasses yield stability, soil erosion, water usage, and labour conditions (Seufert and Ramankutty, 2017). Furthermore, these benefits are not solely contingent on the fertilization process but rather on the combination of farming practices and the overall management system. These advantages are, in essence, a result of the broader production system.

Even if organic fertilisers have significant and demonstrable impacts on certain societal challenges at a local scale, the analysis did not uncover strong evidence of how the most urgent societal challenges are being prioritized through full consultation with rights holders and beneficiaries.

1.2 The societal challenges addressed are clearly understood and documented

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Even though societal challenges related to fertilization processes are generally understood at the global and national levels, no strong evidence was found about how drivers of and responses to societal challenges are identified at the local context.

In this regard, while farming communities often possess highly valuable knowledge of fertilizing processes, comprehensive text-based documentation is not commonly mainstreamed. Furthermore, even if there is typically a deep understanding of agroecosystems, it cannot be assumed that the full extent of the interconnections and impacts between their activities and the natural environment, or between their businesses and the broader socio-economic context, is completely known and clear.

1.3 Human wellbeing outcomes arising from the NBS are identified, benchmarked and periodically assessed

Even though the quantitative and qualitative outcomes related to human well-being resulting from organic fertilizers are identified in general terms in connection with the development of the bioeconomy and human health, no strong evidence was found regarding the benchmarks and periodic assessments used to monitor these outcomes.

The lack of evaluation of organic fertilization initiatives derived from biowastes can be attributed to several factors, including a lack of awareness, limited resources, insufficient capacity, a focus on agronomic outcomes, and a lack of incentives. While general human well-being outcomes are typically recognized, they are often identified in broad terms without provisions for assessment and are frequently only partially integrated into the fertilization strategy at the local level.

Criterion 2. Design of NBS is informed by scale

2.1 Design of NBS recognises and responds to the interactions between the economy, society and ecosystems

Using locally available biowastes as an input for an organic fertilizing strategy involves identifying specific interactions between society and ecosystems, because it is a practice that is based on the relation between waste management systems and fertilising processes. These interactions require careful assessment because the quantity, quality, and properties of the fertilizer depend on these processes, which are external to the farm's immediate operations.

Establishing a cohesive connection between the fertilization process and biowaste utilization necessitates integrating waste management information into the design of the fertilization process. This involves considering the evolution of waste management activities over time and evaluating potential impacts on input quality.

When organic fertilization becomes a part of organic or agroecological farm management systems, other interactions emerge among the economy, society, and ecosystems. These interactions can encompass aspects such as product commercialization and the establishment of a network of interdependencies that must be thoroughly understood and managed.

2.2 Design of NBS integrated with other complementary interventions and seeks synergies across sectors

Fertilization practices are always integrated into a broader management system, which includes complementary interventions at the farm level as well as along the value chain (Oberč and Arroyo Schnell,

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

2020). Therefore, the combination of these practices holds significant relevance in terms of societal well-being, impacts, cost-benefit considerations, and the trade-offs between different practice outcomes.

Using bio-waste-based fertilisers requires the identification of synergies between farming and waste management sectors and integrate operatively complementary practices between these sectors at a local level. However, there are knowledge gaps regarding the complementarity and combined performance of this measure with other practices that affect soil health. In this regard, some of the complementary interventions that are usually integrated with organic fertilising are those practices that are required to align the production system with the rules set by EU for organic farming.

2.3 Design of NBS incorporates risk identification and risk management beyond the intervention site

The lives of rural farmers and business operators are greatly affected by numerous unpredictable uncertainties associated with economic, environmental and social dynamics. Several uncertainties and potential negative impacts can affect fertilization processes, leading farmers to adopt risk-averse strategies, such as employing traditional agricultural methods, due to specific risks, even when higher returns are possible (Wang et al., 2022).

Furthermore, due to the general absence of risk regulation measures in society and the lack of effective preventive mechanisms, farmers' livelihoods are vulnerable, and many farmers exhibit strong risk aversion (Wang et al., 2022). In this regard, it's important to note that the drivers of both internal and external risks are often not identified at the local scale and even when there is scientific and local knowledge regarding these risks, they are not always considered in the decision-making processes. Limiting resources on farming condition the implementation of risk management practices and farmers and practitioners often adopt inefficient and passive risk management strategies rather than confront complex agricultural risks. (Wang et al., 2022). Additionally, environmental impacts associated with off-farm fertility sources are often unaccounted for. Addressing these impacts is a crucial knowledge gap that needs to be filled to enhance the assessment of the sustainability of various organic production systems (Maltais-Landry et al., 2019).

Using organic waste for fertilization is associated with certain risks, including challenges in integrating these wastes into agriculture. According to Westerman and Bicudo, (2005), these challenges include:

- Imbalances of nutrients compared to crop needs, relatively low nutrient concentration compared to chemical fertilizers, and variability in nutrient content with the consequent difficulty in quickly determining nutrient content and predicting the availability of nutrients to growing crops.
- Difficult to haul and spread homogeneously and consistently.
- Possible transfer of weed seed.
- Satisfying environmental regulations on application amounts, application timing, and application methods.
- Environmental concerns, such as heavy metal toxicity, emission of ammonia and other gases, odor, and pathogens, emerging contaminants and persistent organic pollutants and food chain contamination.

Compost prepared from organic wastes should be analysed and tested to avoid any soil and food chain risks. Moreover, to prevent the excessive application of organic waste as fertilizer, it's important to consider nutrient demands. Over-application can lead to increased nitrogen mineralization over time, resulting in nutrient loss through leaching or in gaseous form (Sharma et al., 2019).

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Criterion 3. NBS result in net gain to biodiversity and ecosystem integrity

3.1 NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

OF interventions often do not respond to a comprehensive understanding of the current state of the ecosystems involved. The assessment of drivers of ecosystem degradation and biodiversity loss, along with field verification, is typically lacking and even if there are general information about existing land cover and land use is rarely used for assessing the status of the ecosystems in CC initiatives.

When agroecosystem status assessments are conducted, they are frequently based on general information and data sourced from communities, or traditional knowledge, often without field-level validation. Consequently, there is a notable gap in knowledge concerning the ecological state, including soil biodiversity and the factors contributing to ecosystem loss, with limited identification of options for improvement. Moreover, the knowledge about agroecosystems is usually limited to domestic biodiversity and often overlooks wild (non-domestic) biodiversity.

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

There is a general consensus that organic farming increases biodiversity when compared to conventional agriculture, but the magnitude of this effect seems to vary greatly, particularly among organism groups and across landscapes (Tuck et al., 2014).

The benefits of organic management for biodiversity of wildlife on farmland are clear, with a typical increase in organism abundance of 30 to 50% across different taxa (Seufert and Ramankutty, 2017). Organic farming often has positive effects on species richness and abundance; however, the results were variable among studies. On average, organisms were 50% more abundant in organic farming systems, but the results were highly variable between studies and organism groups. Birds, predatory insects, soil organisms and plants responded positively to organic farming, while non-predatory insects and pests did not (Bengtsson et al., 2005). Unregulated and excessive use of chemical fertilizers is known to have adverse effects on soil biological properties, including total microbial activity, as well as the surrounding environment. In contrast, organic waste fertilizers have a positive impact on these soil properties (Sharma et al., 2019).

OF can lead to clear and measurable biodiversity conservation outcomes, but these results are also influenced by other farming practices that significantly affect species diversity. Additionally, there are still significant knowledge gaps in understanding soil biodiversity, which is particularly important when designing fertilization strategies. These knowledge gaps are especially pertinent at the local level.

During the review no strong evidence was found about how the design, implementation and monitoring of OF strategies are not often linked with specific biodiversity targets and the outcomes related to biodiversity and ecosystem integrity and functionality are usually very general, when they exist.

3.3 Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NBS

EU environmental directives mandate Member States to monitor and report data to demonstrate compliance with the directives' objectives and obligations. The most pertinent directives regarding the potential negative impact of OF are the Water Framework Directive, the Nitrates Directive, and the Groundwater Directive. To

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

track progress in achieving the water quality goals established in these directives, Member States must establish monitoring programs and periodically report their results to the European Commission, providing a comprehensive overview of water quality and its trends (Wuijts et al., 2022). This reporting requirement is a common obligation shared by both the Nitrates Directive and the Water Framework Directive, but these monitoring activities have several differences in the thresholds and assessment methodologies and criteria between Member States (Wuijts et al., 2022).

Although there are regional and national monitoring processes in place to assess the potential impacts of fertilization management, the review revealed limited evidence of their mainstream integration into local governance and farm-level fertilization plans. Furthermore, reducing fertilizer dosage or frequency should be the primary response to minimize potential negative impacts. Guidelines and studies in this regard exist, and while fertilizer dosage reduction actions are linked to the results of monitoring processes in several precision agriculture initiatives, there is limited evidence regarding how these practices are integrated into organic fertilization OF.

3.4 Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NBS strategy

OF using locally available biowastes can be a valuable component of a production system that, when compared to conventional farming, aligns more closely with the principles that govern natural ecosystems. It can provide better conditions, particularly for soil biodiversity, to thrive. However, the review did not uncover any evidence of how organic fertilization initiatives specifically integrate actions aimed at enhancing ecosystem integrity or connectivity. No strong evidence was found regarding how OF interventions consider the importance of maintaining ecosystem integrity and connectivity with a perspective that includes actions aligned with these requirements. This oversight may be due to the fact that, at the farm level, OF does not place sufficient emphasis on the reintegration of interconnected natural elements into the agricultural landscape from a broader perspective.

Criterion 4. NBS are economically viable

4.1 The direct and indirect benefits and costs associated with the NBS, who pays and who benefits, are identified and documented

There is a general understanding of how the major costs and benefits are distributed in OF initiatives, but it is not comprehensive since indirect costs and benefits are not always considered and economic analysis is not always completely documented.

Analysing all costs and benefits may be a challenge since it is not easy to determine environmental consequences of alternative fertilization and waste management policies (Westerman and Bicudo, 2005). In this context, it is important to consider how costs are passed on to consumers or public institutions, as well as how risks and negative externalities could impact costs for other stakeholders in the cost-benefit analysis (Sharma et al., 2019).

Organic agriculture systems, which integrate organic fertilizers (OF) as one of their main practices, are widely recognized for their profitability, costs, and benefits (Sharma et al., 2019). More specifically, Vaneeckhaute et al., 2013 demonstrates that agricultural wastes could be profitable and substituting conventional fertilizers by digestate derivatives in different cultivation scenarios can result in significant economic benefits for the farmers. Nevertheless, the lack of economic analysis on these systems highlights the need for further research and studies to assess the long-term economic sustainability of these systems.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

A basic economic analysis, often including the internal rate of return, is a common component of the economic assessment of farming systems. This analysis primarily considers direct costs and benefits, and there is some understanding of the impacts of changes to current regulations and subsidy regimes. However, there are significant gaps in accounting for indirect costs. It is essential to consider that cost-effectiveness can be easily calculated by taking into account the costs and the fertilizing potential, but there are several indirect costs that are often overlooked.

There is evidence that composting organic waste is a commercially viable approach to achieving cleaner production in farming and agricultural products, as demonstrated by Askarany and Franklin-Smith, (2014) Furthermore, utilizing locally available biowastes can contribute to effective waste management, reduce input costs, and enhance economic sustainability. Sharma et al., (2019) also gather how the use of organic wastes as fertilisers are an efficient alternative enabling value addition.

During the review no strong evidence was found about specific calculation of internal rate of return and cost effectiveness studies which includes upfront and recurring direct and indirect costs and the flow of key benefits. There are significant gaps in accounting for indirect costs and benefits and key assumptions have not been tested.

4.3 The effectiveness of an NBS design is justified against available alternative solutions, taking into account any associated externalities

The effectiveness of OF is justified and partially documented when compared to available alternative solutions, although there are still gaps in the analysis. Due to challenges in the economic valuation of indirect benefits and impacts, associated externalities are only partially addressed from an economic perspective

Considering the potential benefits of using organic waste in agriculture, it can be seen as an efficient alternative to inorganic or chemical fertilizers, taking into account that the intensive use of these chemical fertilizers over the past decades to boost crop productivity and achieve higher yields has had adverse effects on soil health (Sharma et al., 2019).

Sharma et al., (2019) also discuss how adding compost is one of the most cost-effective strategies for soil bioremediation when compared to conventional and more expensive physical and chemical technologies, considering that it helps to reduce the cost and the need for the storage and treatment of these wastes. Economically, the agricultural use of organic wastes decreases landfill costs, waste transportation expenses, imports, and the production costs of chemical fertilizers, while also creating opportunities for rural employment. Crowder and Reganold, (2015) found that, despite lower yields, organic agriculture was significantly more profitable than conventional agriculture and has room to expand globally.

Additionally, Sharma et al., (2019) identifies several studies that estimate the reduced costs for OF and organic farming in waste management and fertilizer use, compared to conventional methods (Sharma et al., 2019).

4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

Organic fertilizing considers a diverse range of resourcing options, with the primary funding deriving from the market. This shift in investment relies on farmers' income generated from sales, and the associated costs are

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

transferred to consumers. Moreover, when integrated into organic farming production systems, farmers can benefit from the increasing demand for organic agricultural products.

Under the CAP, farmers have financial support aimed at optimizing their fertilizer usage, with the objective of helping them achieve environmental, climate, and economic benefits. Furthermore, compliance with regulations and standards pertaining to organic farming is essential for accessing specific markets and certifications. Therefore, a component of the resourcing options portfolio should encompass actions and resources dedicated to ensuring adherence to these requirements. This may involve investments in organic certifications and audits to guarantee that fertilization practices align with established standards

However, during the review no strong evidence was found about a comprehensive review of resourcing options that covers the costs of delivery of the intervention's primary and ancillary benefits has been undertaken.

Criterion 5. NBS are based on inclusive, transparent and empowering governance processes

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention can be initiated

The evaluation did not uncover any evidence related to specific feedback and grievance resolution mechanisms that have been developed as part of organic fertilizing practices through a comprehensive consultation with the affected stakeholders. Additionally, there is a lack of clear evidence regarding ownership and trust in these mechanisms. As a result, it is not possible to assess whether these mechanisms are considered legitimate, accessible, predictable, equitable, transparent, rights-compatible, or adaptively managed.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)

Organic farming has demonstrated several sociocultural strengths, such as fostering positive transformations in community economic development, promoting increased social interactions between farmers and consumers, expanding employment opportunities for farm workers, and fostering greater collaboration among farmers (Reganold and Wachter, 2016). In this regard, organic certification programmes have adopted social wellbeing goals related with working conditions (Reganold and Wachter, 2016).

Nevertheless, achieving inclusive governance and the equitable integration of stakeholders, including workers and consumers, in decision-making processes, remains a challenge in the context of organic farming and organic fertilizing practices. Particularly, the labour aspect of organic farming exhibits higher uncertainty in its performance (Seufert and Ramankutty, 2017). This uncertainty is linked to the absence of mechanisms that ensure traditionally excluded groups are actively and respectfully engaged in the process while upholding their equality, dignity, and encouraging their participation. Available data suggests that both organic and conventional farming systems need to make significant strides to align with social sustainability goal (Seufert and Ramankutty, 2017).

5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

Farmers, landowners, and local waste management entities usually participate in the design and implementation of fertilizing processes, advocating for their own rights and interests. However, there is limited

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

evidence regarding the engagement and participation of stakeholders who may be directly or indirectly affected, either positively or negatively, by this process, such as consumers or local communities.

National and EU policy-making processes typically involve public participation, but not all processes within OF consider the potential negative impacts on stakeholders who often do not feel a sense of ownership over fertilizing interventions. In this regard, there have been limited initiatives that have discussed about the internal mechanisms of various stakeholders within the food waste management system. Furthermore, only a few works have applied stakeholder analysis within the context of OF (Xu et al., 2016). The primary cases identified were associated with research activities in developing countries rather than being linked to the productive cycle of farming (Adil et al., 2022; Prasetyaningtyas et al., 2019).

5.4 Decision-making processes document and respond to rights and interests of all participating and affected stakeholders

Throughout the review, we did not find robust evidence regarding how OF comprehensively maps the rights and interests of all or some participating and affected stakeholders, nor did we uncover strong evidence of how the key steps in OF decision-making procedures are adequately documented in a transparent and accessible manner. However, it's worth noting that when organic fertilization is integrated into an organic farming system, there tends to be a higher level of documentation, and this information is shared with relevant institutions.

5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NBS

During the review, no evidence or information was found regarding how OF initiatives establish mechanisms to enable joint decision-making when the scale of the intervention extends beyond jurisdictional boundaries.

Criterion 6. NBS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

Soil management involve a multitude of decisions, with farmers typically having various options at their disposal. The choices they make and the outcomes that result are influenced by a broad spectrum of economic and environmental objectives and constraints.

Identifying methods to sustain farm yield profitability while simultaneously reducing adverse environmental impacts is a complex challenge due to the interactions and feedback loops among various agricultural practices (Maltais-Landry et al., 2019).

The primary trade-off under consideration in organic farming (OF) is between short-term crop economic performance and yields and the environmental impact of the practice (Maltais-Landry et al., 2019). Additionally, there are significant trade-offs between carbon inputs and the emissions of greenhouse gases and other pollutants (Bos et al., 2017).

In this context, the effective management of organic farming (OF), which encompasses decisions such as dosage, frequency, and others, serves as the primary corrective measure for regulating the fertilization process

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

in accordance with established thresholds, including legally defined limits, to minimize adverse impacts. Costs and benefits are identified, as demonstrated in Sharma et al., (2019); however, this information is not consistently and systematically utilized to inform protective measures and corrective actions.

Moreover, there exists a significant knowledge gap in our understanding of how better environmental practices within organic systems affects yield and environmental conditions (Seufert and Ramankutty, 2017). Therefore, it is critical to identify farming systems that effectively manage nutrient resources, examining the relationship between crop productivity and farm benefits and the impact on ecosystems (Maltais-Landry et al., 2019).

Furthermore, there is a substantial knowledge gap in our understanding of how improved environmental practices within organic systems impact crop yield and environmental conditions (Seufert and Ramankutty, 2017). Therefore, it is crucial to identify fertilization practices that proficiently manage nutrient resources and explore the interaction between crop productivity and farm benefits, and impacts on ecosystems (Maltais-Landry et al., 2019).

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected

The ownership of land is closely linked to farmers' decision-making regarding the application of organic fertilizers, taking into account factors such as the type, stability, security, and integrity of the land. In this context, when comparing their own contracted cropland with subcontracted land, farmers often tend to increase the use of organic fertilizer inputs (Xu et al., 2014).

The limited duration of land tenure often results in short-sighted decisions and the irresponsible use of land resources for immediate, short-term gains. Consequently, farmers with temporary land rights are more inclined to use chemical fertilizers. On the other hand, farmers with permanent land rights tend to consider the potential long-term adverse effects of chemical input usage, which makes them less likely to apply chemical inputs (Nkamleu and Adesina, 2000).

6.3 Established safeguards are periodically reviewed to ensure that mutually-agreed trade-offs limits are respected and do not destabilise the entire NBS

Fertilization practices must adhere to the limits set by various legal and regulatory provisions, and the dosage of fertilizers must meet the established requirements to effectively manage risks and prevent adverse consequences.

However, even if organic fertilizers play a role against overfertilization and despite clear limits established by regulations, guidelines, and fertilizer providers, overfertilization remains a significant concern (Stigter, 2011). During the review, we did not find strong evidence regarding how safeguards are reviewed and systematically documented. Additionally, there is a need to incorporate additional safeguard measures to specifically address the potential side effects that may arise during the transition from synthetic to organic fertilization, particularly in terms of crop yields.

Criterion 7. NBS are managed adaptively, based on evidence

7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

Co-funded by the European Union

UK Research and Innovation

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

While some OF strategies outline intended outcomes, actions, and assumptions, the analysis did not find strong evidence regarding how these strategic aspects are established at the local level as a foundation for monitoring and evaluation. OF is often situated within the context of a circular economy, bioeconomy, and implemented as one of the practices within agroecology, organic farming, permaculture, circular agriculture, or nature-inclusive agriculture farming systems (Oberč and Arroyo Schnell, 2020). While these approaches provide a pathway for addressing societal challenges and include the rationale behind interventions (European Commission, 2018), they are not inherently linked with monitoring and evaluation activities. In this regard, climate-smart agriculture, precision agriculture, or ecological intensification are alternative approaches that more effectively integrate monitoring and evaluation processes (Oberč and Arroyo Schnell, 2020).

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

Throughout the review, no compelling evidence was discovered regarding the systematic and explicit integration of monitoring and evaluation planning within OF at the local scale. However, there are various initiatives at the national and European levels focused on comprehending the extent of organic farming implementation and monitoring soil health status.

A monitoring framework has been established to provide circular economy indicators across five thematic areas: production and consumption, waste management, secondary raw materials, competitiveness and innovation, and global sustainability and resilience (EUROSTAT, 2023). However, these indicators are currently available only at the EU scale, with no specific information provided for individual EU countries. Furthermore, there is a lack of access to specific organic fertilization indicators at the regional and local levels. Additionally, a set of 28 agri-environmental indicators have been developed to track the integration of environmental concerns into the Common Agricultural Policy (CAP) at the EU, national, and regional levels (EUROSTAT, 2023). This set includes information about mineral fertilizers, the surface area dedicated to organic farming, and manure storage. However, there is no specific information available regarding organic fertilizers.

In July 2023 the European Commission submitted a new proposal for a Soil Monitoring Law. This law aims to create a robust soil monitoring framework across Europe and characterise the current state of soil health, addressing the current lack of information. In this regard, Member States will need to assess the status of their soils through measurements taken within specific soil districts (European Commission, 2023).

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

Several learning frameworks support adaptive management in organic fertilizing initiatives. Capacity building and knowledge transfer regarding the benefits of proper organic waste management in agriculture, along with the support of neighbouring farmers, are processes gaining relevance in promoting acceptance by others (Westerman and Bicudo, 2005).

Furthermore, specific approaches like Climate Change Adaptation management systems, such as Climate Smart Agriculture, offer a valuable framework for adaptive agriculture management in the face of a changing climate (Shea, 2014). Precision Agriculture, which is highly focused on adaptive management, also has the potential to provide a framework for iterative learning in initiatives cantered around organic bio-waste-based fertilization. However, its development in OF context is currently limited.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Criterion 8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

8.1 NBS design, implementation and lessons learnt are shared for triggering transformative change

During the review no strong evidence was found about how lessons learnt from design and implementation of organic fertilising from biowastes initiatives have been systematically gathered and shared. There are some communication strategies about OF interventions included in wider communication initiatives related with circular economy strategies and organic farming and other sustainable agriculture systems, but there are less initiatives specifically focused in OF.

The change in farming practices has been the subject of extensive study, with an analysis of how various factors, beyond subsidies and technical evidence, impact farmer behaviour. These factors include the farmer's background, education, access to extension services, participation in policymaking, social norms, and psychological factors (Daadi and Latacz-Lohmann, 2021, Li et al., 2022, Xie et al., 2021). However, there is a lack of information regarding how transformative change could be specifically associated with OF.

8.2 NBS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming

Utilizing compost, vermicompost, sewage sludge and other different wastes as soil amendment is an integrative approach to comply with several policies and strategies related with waste management, bioeconomy, circular economy among others (Sharma et al., 2019).

Organic fertilization using locally available bioproducts is an activity that can be supported by the I Pillar of the EU's Common Agricultural Policy (CAP) if Member States develop the Organic Farming Practices Eco-scheme. Additionally, the European Agricultural Fund for Rural Development (EAFRD), under Pillar II of the CAP, could be also a relevant instrument for supporting organic fertilization and organic farming in general terms.

There are additional regulations that have an impact on organic fertilising activities. Biowaste management and waste-derived product utilization are also regulated in the Waste Framework Directive. The Nitrates Directive form an integral part of the Water Framework Directive and is a key instrument for the protection of water quality, which is threatened by unsuccessful efforts in closing the nutrient loop and excessive use of fertilizers on agricultural land. Accordingly, the EU fertilizer Regulation sets the quality criteria for waste materials and products to comply before they are labelled as organic fertilizers, replacing mineral fertilizers in the market, which has not a high impact on local markets (Angouria-Tsorochidou et al., 2021). The Circular Economy Action Plan, the European Bioeconomy Strategy, and the Bioeconomy Action Plan would be other EU mechanisms that have an indirect effect supporting organic fertilization, as they establish a framework for the recovery of biowastes and their utilization as products (Chojnacka et al., 2020).

8.3 Where relevant, NBS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

OF, when integrated into organic farming systems, contributes to one of the primary objectives set by the EU. The Farm to Fork strategy emphasizes that the EU aims to expand the reach and market share of organic

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

products through the measures outlined in the Action Plan for the Development of Organic Production. The overarching goal within the framework of this Action Plan is to have a minimum of 25% of the EU's agricultural land farmed organically by 2030.

OF also indirectly contributes to several of the SDGs, but it is particularly aligned with Goal 2 (Zero Hunger). It can play a partial role in achieving SDGs related to the preservation and enhancement of our natural environment (SDGs 6, 12, and 13) and contribute to the protection and support of biodiversity (SDGs 14 and 15).

9.2 Cover crops

Cover crops are a close-growing crop that provides soil protection between periods of normal crop production. Cover crops can enhance soil conservation, climate resilience and improve soil health, all the while mitigating various environmental impacts linked to conventional soil management in agriculture.

Criterion 1: NBS effectively address societal challenges

1.1 The most pressing societal challenges for rights holders and beneficiaries are prioritised

Cover crops play a crucial role in promoting climate resilience by assisting farmers in adapting to climate-related risks, while also mitigating numerous environmental impacts associated with conventional tillage and the heavy use of fertilizers in monocultural agriculture (Yoder et al., 2021). In this context, cover cropping is considered a soil conservation practice as it has the potential to improve soil structure, enhancing moisture infiltration, organic matter and retention capacity, thereby reducing soil compaction, erosion, and mitigating drought stress (Lal, 2015; Bergtold et al., 2019).

Furthermore, cover crops can play an integral role in climate change mitigation by enhancing carbon sequestration and provides various ecosystem services and co-benefits related to water cycle regulation, nutrient cycling efficiency, as well as soil pests and disease management (Yoder et al., 2021; Lal, 2015; Bergtold et al., 2019).

The positive impact of cover crops for farmers and the environment has been recognized and promoted by a variety of stakeholders, including agricultural non-profit organizations, private industry, public agencies, farm commodity groups, and farmers themselves. The conservation community widely views cover crops as a win-win opportunity to enhance climate resilience by improving soil conservation, which can be beneficial for both farmers and the environment (Yoder et al., 2021). However, cover crops are also seen as potentially inadequate in addressing the impacts of climate change, as this practice can introduce new risks and management difficulties that might exacerbate the effects of climate change on agricultural production (Yoder et al., 2021).

1.2 The societal challenges addressed are clearly understood and documented

Climate change mitigation and adaptation, land degradation, and soil erosion are some of the main societal challenges addressed by CC. The drivers of these challenges and how they respond to CC are well understood and documented on a broader scale. However, knowledge gaps often exist at the local level, and there is a lack of understanding regarding how each specific intervention responds to these challenges in a particular context. Additionally, the impact of CC on these challenges should not be viewed in isolation but in relation to the entire management system, considering the combined effects of a specific combination of practices. While

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

farmers possess highly valuable knowledge about the impact of production and management practices, comprehensive text-based documentation is not common, especially at the local level.

1.3 Human wellbeing outcomes arising from the NBS are identified, benchmarked and periodically assessed

Even though the human well-being outcomes related to the societal challenges already mentioned, which arise from cover crops, are identified in general terms, no strong evidence was found regarding the benchmarks and periodic assessments used to monitor these outcomes. Outcomes for human well-being are typically recognized, but they are often described in general terms without clear measures for assessment. They are frequently only partially integrated into the farm management strategy, which usually focuses on direct agronomic outcomes. SMART targets for human well-being are not commonly integrated into farming systems as components of an accounting and assessment framework.

Criterion 2. Design of NBS is informed by scale

2.1 Design of NBS recognises and responds to the interactions between the economy, society and ecosystems

Roesch-McNally et al., (2018) describe that integrating a systemic approach and focusing on multiple aspects of management is a common way to incorporate cover crops into cropping systems and overcome adoption barriers. In this context, farmers employ innovative cover crop management strategies as part of a holistic approach to overcome structural constraints, such as a lack of facilitating infrastructure for alternative crops. However, it is clear that row crop farmers are embedded in larger commodity value chains that limit flexibility and shape the choices they can make (Roesch-McNally et al., 2018).

The design of cover crops recognizes and responds to some of the interactions between the economy, society, and ecosystems, although knowledge gaps remain, and interactions do not always inform the design of farming practices. These interactions are only partially or not at all considered in integrated decision-making processes. Some of the interactions that are taken into account are related to the need for labour, the effects on soil and water conservation and quality, and the mitigation of various weather-related risks.

2.2 Design of NBS integrated with other complementary interventions and seeks synergies across sectors

CC are always integrated into a broader management system, which includes complementary interventions at the farm level as well as along the value chain (Oberč and Arroyo Schnell, 2020). Therefore, the combination of these practices holds significant relevance in terms of societal well-being, impacts, cost-benefit considerations, and the trade-offs between different practice outcomes.

CC may indeed be one practice to enhance field and landscape-scale diversification across the region, particularly because cover crops are a complementary practice to extended rotations and crop and livestock integration (Roesch-McNally et al., 2018). Farmers who have more diverse operations, including livestock or additional crops, can integrate CC more successfully into their operations, even if they often feel constrained by larger barriers that shape farm management strategies (Roesch-McNally et al., 2018).

It can be concluded that the design of CC acknowledges and responds to some of the interactions between the economy, society, and ecosystems, although there are remaining knowledge gaps.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

2.3 Design of NBS incorporates risk identification and risk management beyond the intervention site

Criterion 3. NBS result in net gain to biodiversity and ecosystem integrity

3.1 NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

CC interventions often do not respond to a comprehensive understanding of the current state of the ecosystems involved. The assessment of drivers of ecosystem degradation and biodiversity loss, along with field verification, is typically lacking and even if there are general information about existing land cover and land use is rarely used for assessing the status of the ecosystems in CC initiatives.

When agroecosystem status assessments are conducted, they are frequently based on general information and data sourced from communities, or traditional knowledge, often without field-level validation. Consequently, there is a notable gap in knowledge concerning the ecological state, including soil biodiversity and the factors contributing to ecosystem loss, with limited identification of options for improvement. Moreover, the knowledge about agroecosystems is usually limited to domestic biodiversity and often overlooks wild (non-domestic) biodiversity.

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

Several studies suggest that cover crops have the potential to enhance biodiversity, improve environmental outcomes, and increase crop diversity in agricultural systems (Roesch-McNally et al., 2018; Abad et al., 2021). While the specific results may vary depending on the particulars of the cover crop practices, such as termination or tillage methods employed in each context, the use of cover crops leads to an increase in soil microbial diversity. Specifically, cover cropping can significantly enhance parameters of soil microbial abundance, activity, and diversity by 27%, 22%, and 2.5%, respectively, compared to leaving the soil bare fallow (Kim et al., 2020). Furthermore, cover crops have been shown to produce an increase in biodiversity among arthropods, birds, and small mammals (Abad et al., 2021).

CC are either self-terminated in one of several ways: they may either self-terminate over the winter, be actively terminated using herbicides or mechanical methods (e.g., crimping, rolling, cutting), or be ploughed under before planting the production crop. It's worth noting that certain termination practices may have negative impacts on biodiversity and constrain the effectiveness of other soil conservation practices that are being implemented (Roley et al., 2016). Additionally, Shackelford et al., (2019) points out the absence of monitoring and assessment activities of biodiversity outcomes and ecosystem integrity and the lack of data to quantify the effects of cover crops on biodiversity conservation, pollination, or pest regulation.

3.3 Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NBS

During the analysis, no strong evidence was found regarding how monitoring activities are in place to assess adverse consequences on nature arising from CC, especially at the local level. At this scale, some monitoring activities could be just associated with the economic performance of the farming system. Additionally, there is a deficiency in effective response actions linked to the results of the monitoring processes aimed at minimizing and mitigating unforeseen risks that could undermine the ecological foundations of CC.

Co-funded by the European Union

UK Research and Innovation

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

3.4 Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NBS strategy

Cover crops have the potential to enhance biodiversity conservation by promoting a farming system that, in comparison to conventional farming, aligns more closely with the principles that govern natural ecosystems. In this regard, cover crops are commonly integrated into conservation management systems, agroecology, permaculture, biodynamic agriculture, organic farming, among others (Oberč and Arroyo Schnell, 2020), and to a certain extent, this provides better conditions for the species that contribute to ecosystem services to thrive.

However, during the analysis, no strong evidence was found regarding how cover crops, as a specific practice, systematically consider opportunities to enhance ecosystem integrity and connectivity, and the actions aligned with these requirements that are implemented.

Criterion 4. NBS are economically viable

4.1 The direct and indirect benefits and costs associated with the NBS , who pays and who benefits, are identified and documented

Economic considerations related to the decision to adopt or use cover crops are complex, since producers must take into account direct benefits, direct production costs, indirect benefits, indirect and opportunity costs, risk and agricultural policy considerations and externalities, such as social and environmental benefits of reduced soil erosion and chemical runoff (Bergtold et al., 2019).

Roley et al., 2016 and Bergtold et al., (2019) provide a detailed identification and documentation of costs and benefits, including both financial and non-financial aspects, along with a clear description of indirect costs and benefits. However, the magnitude of these benefits is context specific and depends on factors such as cropping system, management, soil type, and weather. Additionally, cover crops have been identified as a practice to reduce input costs for fertilizers, herbicides, and pesticides, and to promote reduced tillage operations and they also hold potential as biofuel feedstock and offer other indirect benefits, such as an increase in soil organic matter (Shackelford et al., 2019; Yoder et al., 2021 and Bergtold et al., 2019).

Given that input costs are the primary economic barrier to using cover crops, and there may be a conflict with the current production system that aims to minimize production costs associated with a single crop in a specific growing season (Roesch-McNally et al., 2018), the reduction in the variability of the main crop yield could be one of the most compelling incentives for adopting cover crops (Bergtold et al., 2019).

However, even if costs and benefits are clearly identified, current literature on the valuation of cover crops benefits is scarce and indirect benefits are not always considered (Bergtold et al., 2019). Although numerous factors may contribute to the variable results reported in the literature, a comprehensive quantitative analysis of how several factors affect crop yield variability and other ecosystem services associated with cover crops is still lacking (Daryanto et al., 2018). Despite of the fact that each producer will weigh the trade-offs differently, there is evidence that cover crops can be managed profitably (Bergtold et al., 2019).

However, even if there is evidence that cover crops can be managed profitably (Bergtold et al., 2019), the current literature on the valuation of cover crop benefits is scarce, and indirect benefits are not always taken into consideration (Bergtold et al., 2019). While several factors may contribute to the variable results reported in the literature, there is still a lack of comprehensive quantitative analysis on how multiple factors affect crop yield variability and other ecosystem services associated with CC (Daryanto et al., 2018).

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

Several studies have analysed how cover crops are a cost-effective practice for mitigating crop decline in perennial monocultures, controlling erosion, reducing nitrogen and phosphorus losses, and preventing leaching (Vukicevich et al., 2016; Roley et al., 2016; Swanson, et al., 2018 and LaRose and Myers, n.d.)

However, more direct experimental investigation in perennial agroecosystems is needed, and there are significant gaps in accounting indirect costs and benefits.

4.3 The effectiveness of an NBS design is justified against available alternative solutions, taking into account any associated externalities

The main alternatives to CC include using spontaneous vegetation or mulch as a cover (Beniaich et al., 2023) or conventional practices where the soil is not covered during significant stages of the cropping cycle. Furthermore, it's essential to consider that cover cropping encompasses various alternative management options that can lead to different outcomes and results depending on how the practice is integrated into the overall management system (Sumberg and Giller, 2022).

The effectiveness and affordability of cover cropping can be broadly justified, and viable alternative solutions have been identified, with their pros and cons documented. However, there are still gaps in the analysis, particularly concerning a comprehensive understanding of the costs, benefits, and risks associated with the complex set of farming practices implemented.

4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

CC considers a diverse range of resourcing options, with the primary funding deriving from the market. This shift in investment relies on farmers' income generated from sales, and the associated costs transferred to consumers. The income directly generated from cash cover crops has to be considered here.

Under the CAP, farmers have financial support to implement practices that follow standards relevant to soil management, called GAECs (Good Agricultural and Environmental Conditions), which are designed to promote beneficial soil practices. Soil cover is one of these GAECs: “Minimum soil cover to avoid bare soil in periods that are most sensitive”. Additionally, Member States can also spend Pillar 2 payments on measures which could encourage farmers to shift towards CC.

However, during the review no strong evidence was found about a comprehensive review of resourcing options that covers the costs of delivery of the intervention's primary and ancillary benefits has been undertaken.

Criterion 5. NBS are based on inclusive, transparent and empowering governance processes

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention can be initiated

No evidence was found during the evaluation regarding the existence of specific feedback and grievance resolution mechanisms that have been developed as part of cover crop practices in full consultation with affected stakeholders, and which demonstrate clear evidence of ownership and trust in the mechanism.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Consequently, it is not possible to assess whether these mechanisms are perceived as legitimate, accessible, predictable, equitable, transparent, rights-compatible, or adaptively managed.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)

During the review, no information was found about the integration of participatory processes in cover crop governance.

5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

Farmers and landowners usually participate in the design and implementation of soil management practices, advocating for their own rights and interests. However, there is limited evidence regarding the engagement and participation of stakeholders who may be directly or indirectly affected, either positively or negatively, by this process, such as consumers or local communities.

5.4 Decision-making processes document and respond to rights and interests of all participating and affected stakeholders

During the review, no evidence or information was found regarding how CC initiatives establish mechanisms to enable joint decision-making when the scale of the intervention extends beyond jurisdictional boundaries.

5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NBS

During the review, no significant evidence was found regarding how CC establish mechanisms to enable joint decision-making when the scale of the intervention extends beyond jurisdictional boundaries.

Criterion 6. NBS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

Cover crop benefits can contribute to achieving economical sustainability and mitigating negative environmental impacts, such as soil erosion or chemical runoff. However, the impact on farm economics, including farm profits and cash crop yields, is often the strongest incentive for adopting cover crops (Bergtold et al., 2019). In this context, economic gains or losses are closely tied to cash crop prices and input costs for both cash and cover crops. These factors can increase short-term risks and may hinder adoption. On the other hand, cover crops may help reduce long-term risks and stabilize cash crop yields. Consequently, producers may face a trade-off between short and long-term risks when deciding whether to adopt cover crops (Bergtold et al., 2019).

Therefore, the use of a cover crop can be in conflict with the current production system that aims to minimize production costs associated with a single crop in a specific growing season (Roesch-McNally et al., 2018), since trade-offs associated with cover crops highly depend on the time scale of the analysis, and producers may face a trade-off between short-term and long-term risks when deciding whether to adopt cover crops

Co-funded by the European Union

UK Research and Innovation

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

(Bergtold et al., 2019). Daryanto et al., (2018) also identifies and analyses other specific trade-offs associated with production and conservation goals and suggests some mitigation measures.

The positive and negative economic impacts on cash crop yields following the use of a cover crop are well-documented, but further research is needed to optimize field management and consider indirect effects (Bergtold et al., 2019). In this context, the assessment of how farmers evaluate the trade-offs among the various reasons that encourage or discourage them from adopting cover crops has not been extensively examined in many studies (Yoder et al., 2021).

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected

Cover crop initiatives generally take place on privately owned land, following the established legal frameworks related to land ownership. Roesch-McNally et al., (2018) emphasizes the significant role of land tenure in influencing farmers' decisions regarding particularly for practices that yield long-term benefits such as CC. The study points out that landowners have a stronger incentive to consistently use cover crops and improve their soil resources than those who are renting land. However, during the review, no compelling evidence was found regarding how CC take into account the rights, usage, and access to land and resources, as well as the responsibilities of stakeholders.

6.3 Established safeguards are periodically reviewed to ensure that mutually-agreed trade-offs limits are respected and do not destabilise the entire NBS

Measures aimed at preventing trade-offs associated with cover crops primarily focus on minimizing any adverse effects on the primary cash crop. In this context, the introduction of cash cover crops, where biomass or grain can be sold as marketable products, has the potential to increase the farmer's gross margin while improving the environmental impact of agricultural practices (Cecchin et al., 2021). The findings from Cecchin et al., (2021) suggest that the introduction of cover crops still requires optimization of field management practices to avoid adverse consequences. Specifically, the study highlights the need for further research to identify: 1) optimal seeding windows to ensure the successful establishment of the cover crop ;2) fertilization rates that minimize nutrient losses and greenhouse gas emissions without compromising seed yield; 3) specific cultivars that reduce overlapping time and 5) residue management to prevent soil depletion.

Other safeguard practices also involve integrating livestock and grazing, as well as forage opportunities, cost-sharing, and specific termination practices, considering the means and timing for terminating the cover crop (Roesch-McNally et al., 2018). Furthermore, combining other conservation agriculture practices with cover cropping can potentially enhance overall water use efficiency and improve the economic trade-offs or reduce risks (Mitchell et al., 2015).

However, during the review, no substantial evidence was found regarding the consideration of mutually agreed-upon trade-off limits and how safeguards are reviewed and monitored.

Criterion 7. NBS are managed adaptively, based on evidence

7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

Cover crops articulate intended outcomes and provide a reasoning about how these objectives should be achieved through management options. This strategy is established to outline certain intended outcomes,

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

actions, and assumptions often aligned with broad approaches to sustainable agriculture, such as agroecology, biodynamic agriculture, ecological intensification, and conservation agriculture, among others (Oberč and Arroyo Schnell, 2020). These strategic approaches are typically context-specific and are informed by the prevailing economic, social, and ecological conditions at each specific site where they are implemented but they are not inherently linked with monitoring and evaluation activities. In this regard, climate-smart agriculture, precision agriculture, or ecological intensification are alternative approaches that more effectively integrate monitoring and evaluation processes (Oberč and Arroyo Schnell, 2020).

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

There are several technical, administrative, research, and policy initiatives related to cover crop monitoring and evaluation that are in place. In this regard, Fendrich et al., (2023), provides a clear overview of these issues at a European scale and has been the main source for assessing this indicator.

Firstly, there are several EU instruments that serve as large-scale spatial databases, including the Integrated Administration and Control System (IACS), the Land Parcel Identification System (LPIS), and the Geospatial Aid Application (GSAA). These databases contain annual declarations submitted by EU farmers for CAP measures and, in some cases, allow for the monitoring of secondary crops or cover crops (Fendrich et al., 2023). However, the consistency of this monitoring varies across Member States, as each national CAP strategic plan influences how farmers make their declarations. The Land Use/Cover Area frame statistical Survey Soil (LUCAS) field survey has limitations for CC monitoring because it is primarily conducted during the main cropping season and, therefore, cannot capture cover crop information (Fendrich et al., 2023)

While there are several initiatives to collect cover crop data, this information is not always publicly available and harmonized at the EU level. As a result, the availability of data regarding their use and presence remains primarily limited to coarse-scale statistical surveys (Fendrich et al., 2023). The most comprehensive information available about cover crops can be found in the Farm Structure Survey (FSS) and the Survey on Agricultural Production Methods, but it does not offer sufficient spatial detail to, for instance, allow a precise assessment of the local impacts of cover crops on soil erosion and carbon content (Fendrich et al., 2023).

There are several remote sensing applications in place, for the spatial monitoring of CC, using specific indexes as NDVI as an indicator of green coverage on the soil, but there are several factors, such as high incidence of clouds, that limit the availability of input data for automated techniques (Fendrich et al., 2023).

There are many remote sensing applications for the spatial monitoring of cover crops, employing specific indexes like NDVI as an indicator of vegetation coverage. Nevertheless, several factors, such as a high frequency of cloud cover and insufficient funding, constrain the accessibility of input data for automated methods and the scalability of these implementations (Fendrich et al., 2023).

Regarding policy initiatives, in July 2023, the European Commission presented a new proposal for a Soil Monitoring Law. This legislation seeks to establish a robust soil monitoring framework across Europe and to assess the current state of soil health, addressing the current lack of information. As part of this initiative, Member States will be required to evaluate the condition of their soils by conducting measurements within designated soil districts (European Commission, 2023).

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

During the analysis, no substantial evidence was found regarding a learning framework that delineates how CC monitoring and evaluation will facilitate adaptive management. Additionally, specific approaches such as Climate Change Adaptation management systems or Climate Smart Agriculture, offer a valuable framework for adaptive agricultural management in response to a changing climate (Shea, 2014). Precision Agriculture, which is highly oriented toward adaptive management, also holds the potential to provide a framework for iterative learning in initiatives centred around CC, although this complementarity is currently limited.

Criterion 8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

8.1 NBS design, implementation and lessons learnt are shared for triggering transformative change

The use of cover crops is not considered as a radical or transformative technology and does not require farmers to make dramatic changes in their management systems and choices of annual cash crops, as cover crops are typically grown during fallow periods (Roesch-McNally et al., 2018).

Despite of the agricultural workshops, publications, technical guides, posts on social media, websites, specialized conferences, training programs, research projects, and farmer networks aimed at promoting cover crops, there is a lack of systematic procedures for capturing and sharing the lessons learned with strategic initiatives in the EU. Farmer networks offer opportunities to learn and share innovative approaches for cover crop management and exchange experiences with other farmers (Roesch-McNally et al., 2018). However, even in the USA, where cover crops have obtained significant attention, farmers and field managers still encounter challenges when trying to engage with farmer networks (Kathage et al., 2022).

Nevertheless, there is a specific understanding of how behaviours change when adopting cover crops. Smit et al., (2019), observed that the concept of cover crops is not yet fully understood by all farmers, and the lack of awareness about the practice and how to implement it is one of the primary reasons that can be deduced from the literature to explain the low adoption of cover crops (Kathage et al., 2022).

8.2 NBS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming

Cover crops are one of the practices considered in the CAP and influenced by several policies at European level. As part of the CAP, Member States must establish a minimum standard for the GAEC 6 (Good Agricultural and Environmental Conditions), which is related with minimum soil cover measures to avoid bare soil in periods that are most sensitive. In doing so, MS define the sensitive period for arable land and the required coverage during the sensitive period considering the peculiarities of their own farming systems, including land uses and soil and climatic conditions. Also, ecoeschemes are one of the mechanisms that CAP stablishes to support positive environmental practices in farming and include cover crops as voluntary measure that offer farmers additional subsidies. (Kathage et al., 2022). Additionally, the European Agricultural Fund for Rural Development (EAFRD), under Pillar II of the CAP, could be also a relevant instrument for supporting cover crops.

The Nitrates Directive is another policy that could be considered as a driver of cover crop as a practice for reducing nitrate leaching. This policy aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface water and by promoting the use of certain farming practices.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

The Directive is implemented by MS, who establish Action Programmes that are compulsory in designated Nitrate Vulnerable Zones. Cover crops has been included in Action Programmes by several MS.

Although much prior research has focused on analysing factors that help predict cover crop use on farms, there is limited research on how farmers navigate and overcome field-level and structural barriers associated with the use of cover crops. The results from the analysis of these conversations suggest that there is a complex dialectical relationship between farmers' individual management decisions and the broader agricultural context in the region that constrains their decisions. (Roesch-McNally et al., 2018)

However, regarding the uptake and mainstreaming of cover crops little is known about farmer adoption behaviour regarding this practice and its relation to policies (Kathage et al., 2022). The reasons for adoption and adoption intensities involved multiple and sometimes contradictory observations, leading to results that are not always clear-cut. Nonetheless, the analysis revealed two principal groups of reasons: (obligatory) policies and (voluntary) agronomic motives, depending on the region. Environmental considerations are not found to be important drivers of adoption (Kathage et al., 2022).

8.3 Where relevant, NBS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

Cover crops are one of the practices included in the Common Agricultural Policy (CAP) as a means to meet the minimum soil cover requirements during the most sensitive periods. These mandatory measures are reported in the annual declarations submitted by EU farmers for CAP compliance.

CC also indirectly contributes to several of the SDGs, but it is particularly aligned with Goal 2 (Zero Hunger). It can play a partial role in achieving SDGs related to the preservation and enhancement of our natural environment (SDGs 6, 12, and 13) and contribute to the protection and support of biodiversity (SDGs 14 and 15). Specifically, cover crops contribute to achieving a Land Degradation Neutrality (LDN) world (target 15.3).

9.3 Paludiculture

Criterion 1: NBS effectively address societal challenges

1.1 The most pressing societal challenges for rights holders and beneficiaries are prioritised

Paludiculture addresses several societal challenges such as climate change mitigation and adaptation, disaster risk reduction, economic and social development, water security and environmental degradation and biodiversity loss (Budiman et al., 2020).

Drained peatlands are a significant source of emissions, and a transition to paludiculture has the potential to reduce greenhouse gas emissions. Additionally, it contributes to the avoidance of carbon dioxide emissions by replacing fossil raw materials and fossil fuels through the production of biomass (Joosten et al., 2016, Ziegler et al., 2021). Peatlands are a unique ecosystem that constitute an important global carbon sink (Ziegler et al., 2021; O'Neill et al., 2022) and they also represent a win-win solution for restoring degraded peatlands and potentially providing new activities that could bring economic and social benefits while simultaneously contributing to climate change mitigation (Rowan et al., 2022; Budiman et al., 2020; Lahtinen et al., 2022).

In addition to the climatic benefits of rewetting and the production of raw materials for industrial and energy use, paludiculture offers several additional advantages, as outlined by (Joosten et al., 2016 and Wichtmann

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

and Joosten, 2007): 1) improvement of regional landscape hydrology, 2) restoration of habitats for rare mire species and communities, as well as the conservation of cultural landscapes, 3) revitalization of rural economies by combining traditional land use with new productive practices, such as (eco)tourism, 4) adaptation to local climate change through increased evaporative cooling, regulation of water dynamics (flood control), and water quality improvement and 5) conservation and restoration of peatland-specific flora and fauna.

Even if paludiculture have significant and demonstrable impacts on certain societal challenges, the analysis did not uncover strong evidence of how the most urgent societal challenges are being prioritized through full consultation with rights holders and beneficiaries.

1.2 The societal challenges addressed are clearly understood and documented

Given that climate change is the primary challenge addressed by paludiculture, it can be considered that the drivers of and responses to the identified societal challenges are well understood, documented, and accessible. There is also extensive documentation regarding how paludiculture can mitigate climate change and deliver ecosystem services. However, it's worth noting that comprehensive assessments of the whole life cycle climate impacts are rarely studied (Lahtinen et al., 2022). Furthermore, uncertainties persist regarding emissions associated with drained peatlands and paludiculture (Lahtinen et al., 2022). These uncertainties are related to impacts at a local scale and also, to its economic performance in the specific contexts where it is to be implemented.

1.3 Human wellbeing outcomes arising from the NBS are identified, benchmarked and periodically assessed

Human well-being outcomes resulting from paludiculture are typically identified and assessed in terms of their impact, although there is still a lack of information regarding the integrated monitoring processes for these interventions.

The potential of paludiculture to restore degraded peatlands and reduce emissions has been assessed as a measure to mitigate drainage impacts. Budiman et al., (2020) and Laishram et al., (2012), among others, have explored and documented this issue, identifying uncertainties in the product life cycle under specific management practices.

Paludiculture delivers several ecosystem services and several benefits to humans related with the provision of food and clean drinking water, the decomposition of wastes, and the resilience and productivity of food ecosystems.

Paludiculture can create new employment opportunities for farmers and offer communities a fair transition to a low-carbon economy, revitalizing rural economies by combining traditional practices with innovative approaches, such as eco-tourism (Rowan et al., 2022).

Criterion 2. Design of NBS is informed by scale

2.1 Design of NBS recognises and responds to the interactions between the economy, society and ecosystems

Paludiculture is viewed within a systemic perspective that acknowledges and facilitates the analysis of environmental, social, and economic aspects at various levels, including the field, farm, landscape, inter-landscape, and even national and international scales. It encourages a comprehensive approach throughout

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

the value chain, emphasizes local and territorial strategies, and fosters consumer awareness. Additionally, it is closely linked with financing and investment mechanisms. For example, paludiculture is presented as a solution that creates economic opportunities, has positive social impacts, and promotes local biodiversity by preserving wetlands, maintaining water levels, and ensuring access to clean water.

Paludiculture recognizes specific interactions between the economy, society, and ecosystems and incorporates these considerations into its management system. Various aspects of paludiculture address the connections between climate finance, the circular economy, and rewetting initiatives (Ziegler et al., 2021).

Paludiculture serves as a valuable strategy for establishing a reservoir of soil water essential for irrigating surrounding areas. This practice not only helps in reducing the substantial costs linked to the construction of crop irrigation systems but also plays a crucial role in mitigating drought-related challenges at both local and regional levels.

In addition, beyond purely productivist approaches, concepts like peatland culture and wet livelihoods have emerged in recent policy developments, exploring the relationship between specific sets of values, conventions, cultural heritage from rural areas, and social practices with particular ecosystems (Ziegler, 2020). In this regard, paludiculture is designed as an economic strategy that, through innovative processes, integrates principles of nature conservation and restoration into its framework (Ziegler, 2020).

During the analysis, several pieces of evidence were found to show how paludiculture is viewed within a systemic perspective that acknowledges and facilitates the analysis of environmental, social, and economic aspects at various levels, including the field, farm, landscape, inter-landscape, and even national and international scales. Paludiculture also incorporates a comprehensive approach throughout the value chain, emphasising local and territorial strategies, and has the potential to raise consumer awareness. Furthermore, it could be associated with carbon credit mechanisms.

2.2 Design of NBS integrated with other complementary interventions and seeks synergies across sectors

Synergies between paludiculture and digital technologies such as IoT, AI, machine learning, big data analytics, and cloud technology have been explored and identified in Rowan et al., (2022). This study also specifies various pathways for wastewater treatment and options for enabling wastewater reuse in paludiculture.

Paludiculture initiatives typically collaborate with other initiatives at the regional, national, and, especially, international levels. The primary goal of these collaborative efforts is knowledge exchange, closely associated with the significant role of the academic sector and scientific activities in paludiculture (Ziegler et al., 2021).

Paludiculture activities integrate a wide range of interventions, including the development of distribution channels for specific products, innovations in tools and machinery for biomass collection, and improvements in harvesting techniques. These initiatives are linked to the adoption of new organizational and management practices, as well as the establishment of new partnerships. Furthermore, paludiculture can be integrated into various value chains, contributing to fuel production for the energy sector, the supply of raw materials for construction, and it also plays a role in recreational activities associated with the eco-tourism sector (Ziegler et al., 2021). Additionally, synergies between paludiculture and other sectors, such as climate finance for rewetting have been explored and several complementary interventions are integrated within its design, but knowledge gaps persist (Ziegler et al., 2021).

2.3 Design of NBS incorporates risk identification and risk management beyond the intervention site

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

The lack of knowledge among policymakers regarding peatland management and the absence of necessary information are among the primary risks identified. These factors can significantly influence the implementation of interventions. In addition, there are risks associated with the requirement for capable institutions to introduce reforms and management options that promote better coordination in the implementation and enforcement of paludiculture. Governance risks are particularly linked to the coordination of rewetting efforts in order to establish an integrated water management system and re-vegetate peatlands, thereby reducing anthropogenic pressures and revitalizing the livelihoods of local communities. This coordination also involves regulating the practices of commercial concession holders to improve living conditions (Budiman et al., 2021).

There are many other risks related to the potential impact of paludiculture on local communities, economic aspects, financial and investment risks, and knowledge risks associated with rewetting practices and the selection of suitable species for inclusion in paludiculture (Budiman et al., 2020). These risks remain highly relevant even as stakeholders' awareness is increasing.

While paludiculture acknowledges various risks, there is a deficiency in the analysis and management of these risks. Specific knowledge gaps in different contexts persist, and there is a shortage of comprehensive documentation.

Criterion 3. NBS result in net gain to biodiversity and ecosystem integrity

3.1 NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

Given that paludiculture is a management system closely associated with scientific research activities, interventions are typically informed by evidence regarding the state of ecosystems. This evidence is generally verified through field visits and often involves input from local communities in several cases (Ziegler et al., 2021).

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

Numerous studies highlight that paludiculture yields clear outcomes related to biodiversity conservation and ecosystem integrity, since the reestablishment of mire and mire-like conditions after rewetting will create new habitats for wild plant species. From a perspective of species and habitat conservation, rewetting degraded peatlands is generally preferable to keeping the areas drained and degraded (Wichtmann and Joosten, 2007).

Joosten et al., (2016) gather evidence about how paludiculture supports typical peatland biota, particularly when mowing does not occur annually, and they point out that several red-listed plant species can become established within a few years.

Tanneberger et al., (2023), in a preprint that has not yet undergone peer review, provides evidence that paludiculture sites are likely to host greater fen biodiversity and more wetland species compared to their drained state. In this context, even species typically found in agricultural or open landscapes may benefit from peatland rewetting and management due to the subsequent changes in vegetation structure.

Paludiculture sites can support high vegetation diversity, as well as critically endangered breeding birds, spiders, and carabids of conservation concern (Tanneberger et al., 2023). Each taxon is expected to respond differently to management, emphasizing the need for a multi-taxon perspective to understand the impact of paludiculture on the biodiversity of rewetted peatlands. Additionally, without mowing or other forms of

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

management, rewetted fens may become dominated by a few tall and competitive species, resulting in a loss of low-growing plants and rare species (Tanneberger et al., 2023).

The same study gathers evidence about several sites where paludiculture has been implemented and shows that they host species of high international conservation value. In this context, the site with the greatest management influence exhibited both the lowest and the highest qualitative biodiversity values, depending on the taxon. Therefore, further research is needed to understand long-term biodiversity trends in these novel ecosystems.

3.3 Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NBS

There are several initiatives that have established standardized sets of criteria and indicators for informing and monitoring policy outcomes related to biodiversity in paludiculture projects. However, these monitoring criteria and indicators often tend to be highly specific, tailored to the needs and objectives of particular policies and sectors (Reed et al., 2022). There are few examples of their widespread adoption by the research community to rationalize and standardize research and monitoring efforts. Reed et al., (2022) also highlights the development of shared vocabularies and standards that facilitate data sharing and reuse in databases of species traits across various taxa and for species occurrence data, as well as in broader soil and water contexts.

Even if some of these criteria and indicators are associated with unintended adverse consequences on nature resulting from paludiculture, during the analysis, no compelling evidence was found to indicate the presence of monitoring activities that assess adverse impacts on nature arising from paludiculture at the local level and about the measures in place to mitigate those impacts.

3.4 Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NBS strategy

Paludiculture typically involves the rewetting of drained peatlands as a measure to enhance wet ecosystem integrity and restore various processes and services. While paludiculture may not always fully replicate the original biotic integrity, including plant species composition, community structure, and ecosystem function, it does facilitate the restoration of degraded peatlands to a certain extent by reintroducing essential components of wet ecosystems, such as hydrological fluxes and the characteristic vegetation of these habitats (Tata, 2019).

Criterion 4. NBS are economically viable

4.1 The direct and indirect benefits and costs associated with the NBS , who pays and who benefits, are identified and documented

There are several challenges in the identification and documentation of costs and benefits in paludiculture. The economic viability of paludiculture at the farm level remains largely unknown, despite several initiatives aimed at analysing its costs and benefits (Wichmann, 2017).

For many forms of paludiculture, there are still gaps in data concerning costs and revenues. Even for relatively common wet meadows, where detailed information is available, there is still a lack of information regarding the most typical site conditions and biomass yields. Additionally, numerous factors influence costs and benefits, including area size, soil properties, machinery used, and labour input (Wichmann, 2017). Information about

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

product quality is also not highly developed, and this significantly affects the economic benefits generated by paludiculture and, ultimately, its economic viability (Ziegler et al., 2021).

Furthermore, there are significant uncertainties regarding the value of the paludiculture product chain, market demand. Despite the demand, low prices and the dominance of wholesalers in the supply chain create structural barriers and obstacles in the market (Ziegler et al., 2021). Additionally, there is a lack of information regarding the long-term economic success of some of the species used in paludiculture (Budiman et al., 2020). Wichmann, (2017) also highlights the absence of studies with reliable data on the costs of biomass removal based on large-scale and long-term experience with specialized machinery.

Estimating the marginal costs of avoided damage, from a climate adaptation perspective, are one important economic indicator for evaluating the damages of drained and the benefits of rewetted peatlands. Since rewetted peatlands also contributes to climate change mitigation avoiding greenhouse gas emissions have associated specific benefits that also have to be considered (Wichtmann & Schäfer 2007). In this regard, the costs and benefits are easily miscalculated and deterministic accounting using fixed values is restricted to specific cases (Wichmann, 2017).

4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

There are relevant uncertainties regarding the cost-effectiveness of paludiculture. Several studies, such as Budiman et al., (2020) and Joosten et al., (2016) point out that in sites designated for conservation, paludiculture is considered a cost-effective management option that can generate income from both carbon credits and biomass production. However, Ziegler et al., (2021) highlights that most paludiculture initiatives are not yet cost-effective, even though there are options to enhance the competitiveness of paludiculture production.

Nonetheless, in sites designated for conservation, paludiculture should be viewed as a cost-effective management option, serving as an instrumental yet complementary approach to conservation, as emphasized by Joosten et al., (2016).

4.3 The effectiveness of an NBS design is justified against available alternative solutions, taking into account any associated externalities

Paludiculture is designed as an option for reducing greenhouse gas (GHG) emissions while restoring wet ecosystems and providing agricultural production, along with several co-benefits. It has been compared to various alternative solutions. From an economic perspective, most paludiculture initiatives compete with conventional drainage-based agriculture and silviculture, with no direct competition with food production (Schäfer, 2012). Other options aimed at reducing GHG emissions include taking peatlands out of agricultural production and implementing afforestation initiatives or dedicating the land exclusively to conservation (Lahtinen et al., 2022).

Given that paludiculture delivers diverse co-benefits, justifying its effectiveness and affordability compared to available alternative solutions is a complex analysis. However, there has been no comprehensive review of the cost-effectiveness of the proposed intervention against other viable alternatives.

4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

The main resource option focuses on market provision and potential value chains for farmers adopting paludiculture and selling their harvest to companies in construction, energy, and other sectors. This approach is reinforced by economic feasibility in the short term and the income potential within the existing institutional structures (Ziegler, 2020)

Although the primary focus of paludiculture is on commercial use (Ziegler et al., 2021), the market for paludiculture products is evolving and changing (Lahtinen et al., 2022), which introduces uncertainties about the viability of commercial opportunities and funding sources.

Potential income from agri-environmental schemes, such as rewards for environmental services, represents a suitable option for paludiculture, and future funding frameworks need careful consideration (Tanneberger et al., 2022, Budiman et al., 2020).

Given the close links of paludiculture with climate change mitigation and wet ecosystem restoration, other resource options related to climate finance and public funding are also being explored (Ziegler et al., 2021).

While new value chains are essential, they are incomplete if they do not also consider domestic and communal modes of provision for communal land users, municipalities, and the public provision of energy and clean water. In this regard, there is a risk that ongoing paludiculture efforts may not sufficiently explore public, communal, and domestic use options and their transformative potential (Ziegler, 2020).

Criterion 5. NBS are based on inclusive, transparent and empowering governance processes

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention can be initiated

No evidence was found during the evaluation regarding specific feedback and grievance resolution mechanisms developed as part of the paludiculture management system or interventions that were established in full consultation with affected stakeholders, with clear evidence of ownership and trust in the mechanism. There is insufficient information to assess whether these mechanisms are considered legitimate, accessible, predictable, equitable, transparent, rights-compatible, and adaptively managed.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)

There is some evidence of the collaborative and participative structures and dynamics integrated into paludiculture organizational types, along with a significant level of involvement from key institutions and stakeholders (Ziegler et al., 2021).

5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

The collaborative aspect of paludiculture is noteworthy as it typically involves a variety of landowners, stakeholders, and users. Research and academic institutions play a very significant role in these initiatives, and collaborations between research and private enterprises are common (Ziegler et al., 2021). However, there is a lack of information regarding the incorporation of stakeholder analysis into decision-making processes. Additionally, there is limited engagement and participation from stakeholders who might be impacted, whether directly or indirectly, positively or negatively, by these practices.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

5.4 Decision-making processes document and respond to rights and interests of all participating and affected stakeholders

During the review, no clear and readily accessible documentation regarding the decision-making procedures and essential steps for paludiculture implementation was found. This lack of transparency could pose an obstacle to the dissemination of knowledge and best practices in the field, making it challenging for individuals or organizations to make well-informed decisions. Furthermore, there is a gap in information regarding the consideration of stakeholder rights and interests in the decision-making processes related to paludiculture.

5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NBS

During the review, no significant evidence was found regarding how paludiculture establish mechanisms to enable joint decision-making when the scale of the intervention extends beyond jurisdictional boundaries.

Criterion 6. NBS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

There are several studies that point out that paludiculture provides a balance of both ecology and economic benefits (Tata, 2019). Rewetted degraded peatlands reduce GHG emissions, and the restoration of hydrology and rehabilitation of vegetation have been proven to be able to mitigate climate change and at the same time increase community adaptation. Meanwhile, commodities from vegetation rehabilitation and hydrological restoration activities shall provide economic benefits even if few options for wet and rewetted peatland restoration which provides economic benefit (Tata, 2019).

However, integrating both economic and conservation goals is still a challenge for many paludiculture initiatives (Budiman et al., 2020).

Trade-offs were observed between the rewetting of soil to maintain high peat water tables and the need to provide short-term economic benefits for local communities through horticultural and fishery practices in drained areas (Budiman et al., 2020). These trade-offs are identified when selecting suitable species, combining agroforestry practices with fishery activities, and designing practices that align more closely with livelihood goals rather than restoration and conservation purposes. Strategies that successfully achieve both conservation and economic goals remain elusive (Budiman et al., 2020). Additionally, biomass use may conflict with nature conservation, such as when early mowing for biogas production destroys breeding habitats or when winter harvesting leaves insufficient old-growth reed for breeding habitats (Joosten et al., 2016).

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected

At a more basic level, paludiculture mostly appeals to the rights that comes with ownership of land. In this regard, Ziegler et al., (2021) identified that collaboration of stakeholders in paludiculture might be linked to land requirements, since many initiatives are carried out on government- or enterprise-owned land, few on land owned by civil society and indigenous communities.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

However, during the analysis, no strong evidence was found about how rights, usage of and access to land and resources, as well as responsibilities are analysed, acknowledged and respected.

6.3 Established safeguards are periodically reviewed to ensure that mutually-agreed trade-offs limits are respected and do not destabilise the entire NBS

The trade-offs affecting paludiculture are broadly identified, and specific measures to prevent negative impacts are typically in place. This encompasses considerations related to ecological and economic dimensions, such as water levels and peat formation conditions, as well as the economic sustainability of the system (Wichtmann and Joosten, 2007).

However, the evaluation did not uncover sufficient information regarding agreed-upon limits for these trade-offs or specific safeguards to prevent these limits from being exceeded. Additionally, there is a lack of information regarding the periodic review of safeguards and documentation.

In some interventions, there is a trade-off between the goals of increasing community incomes and conserving peat through restoration. Effectively managing these trade-offs in compromised paludiculture necessitates a strategic approach. To ensure alignment with peatland restoration objectives, cultivation practices must be adjusted in response to changes in the water table throughout the season (Budiman et al., 2020)

Criterion 7. NBS are managed adaptively, based on evidence

7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

During the evaluation, insufficient information was found about the explicit establishment of paludiculture strategies, even though the reviewed literature addressed the rationale behind these initiatives, defined their intended outcomes, and explained how they should be achieved through the actions taken.

Paludiculture interventions are typically associated with research and scientific activities, making them valuable sources of essential elements for the development of a strategy that could serve as a foundation for ongoing monitoring and evaluation. In this regard, climate-smart agriculture, precision agriculture, or ecological intensification are alternative approaches that more effectively integrate monitoring and evaluation processes (Oberč and Arroyo Schnell, 2020).

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

While initiatives typically monitor biomass yields, biodiversity, greenhouse gas emissions, and water quality, the absence of a standardized data collection system hinders comparative and meta-analysis efforts. Additionally, in some cases, economic data is not even collected (Ziegler et al., 2021).

In an effort to consolidate and standardize the data used in policy processes, several initiatives have aimed to establish sets of criteria and indicators for informing and monitoring policy outcomes related to biodiversity, but these standards often tend to be highly specific and there are few instances of widespread adoption to mainstream monitoring efforts (Reed et al., 2022).

In the context of paludiculture, several global initiatives focus on data collection, standardization, and reporting for natural resources and biodiversity. These initiatives provide information on terrestrial variables, including

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

the database of northern peatland soil properties and Holocene carbon and nitrogen accumulation, along with the established PeatDataHub and the Eyes on the Bog citizen science initiative (Reed et al., 2022).

In general terms many of the digital technologies, tools and protocols applied to the agriculture sector for monitoring can be also integrated in peatland interventions, including remote sensing data for monitoring biomass production of paludiculture systems, information systems and collection and evaluation of large amounts of data. However, the complexity and diversity of such data is likely to be vast and will require systematic approaches to make digitalization sustainable (Rowan et al., 2022). Eddy Covariance (EC) flux measurements are essential in the context of paludiculture, as they provide real-time, precise data on greenhouse gas exchanges. This enables effective monitoring and evaluation of wetland ecosystems, underpinning their role in climate change mitigation.

Also, there are several EU instruments that serve as large-scale spatial databases wich contain annual declarations submitted by EU farmers for CAP measures and, in some cases, could allow for the monitoring of paludiculture. However, the consistency of this monitoring varies across Member States, as each national CAP strategic plan influences how farmers make their declarations.

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

Paludiculture is primarily driven by scientific research, with research being the key sector initiating paludiculture projects, followed by government and the private sector (Ziegler et al., 2021). Since research plays a leading role in running these initiatives, there are several learning activities institutionalized under scientific and academic processes in paludiculture.

Budiman et al., 2020 also demonstrates how adaptive learning occurs in paludiculture, accompanied by debates among national and local experts. The involvement of research institutions in paludiculture interventions facilitates the application of a learning framework at various stages of the intervention lifecycle, linked to the monitoring and evaluation plan. This, in turn, ensures that management decisions are informed by learning at a certain level.

During the analysis, no substantial evidence was found regarding a learning framework that delineates how paludiculture monitoring and evaluation facilitate adaptive management. Additionally, specific approaches such as Climate Change Adaptation management systems or Climate Smart Agriculture, offer a valuable framework for adaptive agricultural management in response to a changing climate (Shea, 2014). Precision Agriculture, which is highly oriented toward adaptive management, also holds the potential to provide a framework for iterative learning in initiatives centred around paludiculture, although this complementarity is currently limited.

Criterion 8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

8.1 NBS design, implementation and lessons learnt are shared for triggering transformative change

The scientific and research orientation of paludiculture is closely linked to the fact that a significant proportion of initiatives prioritize knowledge exchange as their primary goal of collaboration and many initiatives engage in cooperation at regional, national, and international levels (Ziegler et al., 2021).

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Ziegler, 2020 shows that supporters of paludiculture collaborate with a range of stakeholders, including farmers, potential harvest users, visitors, scientists, funders, coaches, and water management associations. However, there is no pre-existing social network among these groups. Innovators primarily seek to establish networks through international conferences and action groups. Building such networks faces challenges due to the contested nature of land use change, necessitating constructive and inclusive dialogues but established networks like farmers' associations can potentially facilitate land use change through their internal connections and practical knowledge (Ziegler, 2020).

Ziegler et al., (2021) also provides learnings about the transformative and non-transformative approaches to paludiculture and gathers relevant information on the key lessons identified by stakeholders involved in paludiculture initiatives. In this regard, governance is considered a primary issue, emphasizing the importance of involving stakeholders early on to understand the benefits and costs for different actors, reach compromises, and engage in paludiculture education.

8.2 NBS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming

Paludiculture is defined by the CAP as an agricultural activity, making it eligible for direct payments. However, while GAEC 2 aims to protect carbon-rich soils, the actual requirements remain weak because there is no obligation to halt or reverse degradation, and Member States can request a delay in the implementation of GAEC 2 until 2025 (Nemcová and Caiati, 2022).

Furthermore, the CAP stipulates that Member States (MS) should have the option to establish eco-schemes to promote agricultural practices aligned with environmental protection, biodiversity, and groundwater management on agricultural lands (Ziegler, 2020). However, none of the assessed countries have implemented an eco-scheme to support and incentivize paludiculture on formerly drained peatlands. Additionally, the two countries that do have a relevant eco-scheme lack ambition in this regard (Nemcová and Caiati, 2022). MS can also allocate Pillar II payments for agri-environment climate commitments (AECC) to encourage farmers to transition to paludiculture and support ecosystem maintenance and restoration, including advisory services, training, investments, and other support activities.

So far, substantial upscaling of funding for Agri-Environment Climate Measures (AECM) related to peatland rewetting and improved management of drained peatlands has been lacking in most EU Member States and good practice examples are rare. Additionally, none of the assessed countries have planned to allocate Pillar 2 payments to encourage farmers to transition to paludiculture, which could include support for advisory services, investments in specialized machinery for wet soils, or water-logging installations (Nemcová and Caiati, 2022).

Several supporting policies indirectly affect paludiculture, including the EU-Nitrate Directive integrated into the European Water Framework Directive (WFD), the WFD following the polluter-pays principle, and climate change policies that recognize drained mires as a significant source of greenhouse gases, thus enhancing wetland restoration (Ziegler, 2020).

Relevant policies, laws, and regulations are identified and considered in the design of paludiculture interventions, with communication efforts aimed at informing and enhancing policy and regulation frameworks. However, paludiculture lacks development and recognition in policies like the CAP. Knowledge gaps persist regarding the potential use of regulatory and policy mechanisms to promote paludiculture. Regulatory barriers for early adopters remain, despite some identified policy opportunities and impacts.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

8.3 Where relevant, NBS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

Paludiculture aligns with multiple global targets, including the United Nations' Sustainable Development Goals and objectives outlined in the Paris Agreement (Ziegler et al., 2021). More specifically, paludiculture contributes to SDG 6 (Clean water and sanitation), SDG 12 (Responsible production and consumption), SDG 13 (Climate action), SDG 14 (Life below water), and significantly supports biodiversity protection and enhancement, furthering SDGs 14 (Life below water) and 15 (Life on Land).

9.4 Bioremediation

Criterion 1: NBS effectively address societal challenges

1.1 The most pressing societal challenges for rights holders and beneficiaries are prioritised

Biological remediation addresses several societal challenges such as human health, environmental degradation and contamination (Wang et al., 2021).

The increasing pollution of air, soils, groundwater, and surface waters poses a significant threat to public health (Dvořák et al., 2017). Specifically, heavy metals in soil have raised considerable concern due to their toxic effects on both human health and ecosystems. To address this issue, biological remediation is a valuable method for removing these components and mitigating the risks of metal migration. Furthermore, nature-based remediation approaches enhance human well-being by improving aesthetics and offering health benefits. They also hold social value by providing spaces for public recreation (Wang et al., 2021).

Even if bioremediation have significant and demonstrable impacts on certain societal challenges, the analysis did not uncover strong evidence of how the most urgent societal challenges are being prioritized through full consultation with rights holders and beneficiaries.

1.2 The societal challenges addressed are clearly understood and documented

While societal challenges related to soil contamination are generally understood at the global and national levels, there is a lack of strong evidence regarding the identification of drivers and responses to these challenges at the local level. Contaminated sites and heavy metal pollution have become a global environmental problem, and estimations about its impact have been made. However, the extent and nature of diffuse contamination remain largely unknown, making it difficult to quantify the true extent of local soil contamination because many countries lack comprehensive inventories (Panagos et al., 2013).

Nikolić and Stevović, (2015); Ashraf et al., (2019); O'Connor et al., (2019) and Liedekerke et al., (2014) provide a clear understanding about soil pollution and its drivers and potential responses. Drivers of and responses to soil contamination and land degradation are broadly understood within the relevant context although some documentation and knowledge gaps persist specifically at a local level.

1.3 Human wellbeing outcomes arising from the NBS are identified, benchmarked and periodically assessed

Specific human well-being outcomes, related with the absence of pollutants are identified and typically assessed in bioremediation initiatives. However, there is still a lack of information regarding how monitoring

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

processes are integrated into these interventions. Assessments are often conducted at the global, national, and even local levels, incorporating measurements of soil health and the presence of pollutants.

Criterion 2. Design of NBS is informed by scale

2.1 Design of NBS recognises and responds to the interactions between the economy, society and ecosystems

During the review, no strong evidence was found regarding how bioremediation integrates a systemic approach that recognizes and responds to interactions between the economy, society, and ecosystems beyond the pollution processes.

2.2 Design of NBS integrated with other complementary interventions and seeks synergies across sectors

Synergies between bioremediation and other sectors have been explored and several complementary interventions are integrated into its design. However, knowledge gaps persist. While many phytoremediation studies have focused on single plant species, the economic and environmental benefits of intercropping with trees and herbaceous species are well-established. The harvested plant biomass after phytoextraction can be used for bioenergy production (Gómez-Sagasti et al., 2021 and Ashraf et al., 2019).

The emergence of phytomanagement or phytoattenuation as approaches to simultaneously provide economic, social, and environmental benefits in comparison to conventional phytoremediation is seen as an opportunity for a systemic and broad perspective in bioremediation practices. In this cases, risk-based land use is considered the primary objective in phytomanagement, with metal remediation as a secondary aim (Wang et al., 2021).

Additionally, bioremediation, though environmentally friendly, should be combined with renewable resources like wind and solar energy, along with biomass generation for renewable energy resources (Megharaj and Naidu, 2017).

2.3 Design of NBS incorporates risk identification and risk management beyond the intervention site

Several studies, including Wang et al., (2021) demonstrate how bioremediation integrates risk management into the design of remediation interventions. In this context, specific approaches such as green remediation and sustainable remediation have emerged, with risk management practices at their core. They take into account impacts beyond the site boundary. Additionally, Wang et al., (2021) and O'Connor et al., (2019) emphasize the importance of considering secondary impacts, such as environmental risks associated with landfill waste, noise and air pollution during transport and greenhouse gas emissions throughout the entire remediation life cycle, especially over the long term.

Criterion 3. NBS result in net gain to biodiversity and ecosystem integrity

3.1 NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

Bioremediation initiatives respond to the evidence-based assessment of ecosystem contamination. This assessment includes field verification and integrates scientific knowledge about the current environmental

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

conditions. It involves characterizing the ecological state, measuring pollutant concentrations, and identifying improvement options.

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

There are various bioremediation practices, and each have differing impacts on biodiversity. For instance, phytoremediation has demonstrated higher environmental performance, while microbial degradation, bio-electrokinetic remediation, and soil washing may present more significant environmental, economic, and social limitations that can affect overall sustainability (Wang et al., 2021).

Phytoremediation practices have demonstrated effectiveness in stimulating the natural belowground microbial community to remove contaminants and enhance overall soil quality. This occurs not only in terms of decontamination and increased nutrient levels but also through the synergistic interactions between plants and the belowground microbial community (Barra Caracciolo et al., 2020). Gómez-Sagasti et al., (2021) also provides evidence of the potential of mycorrhizal-assisted phytoremediation and intercropping strategies to improve soil health in degraded areas and increase microbial abundance of some taxa.

Indirectly, the removal of stressors, such as reducing pollutant inputs, is a passive restoration intervention that may have a positive impact on biodiversity even if there often fails to recover biodiversity and functions due to legacy contamination and local extinctions (Bugnot et al., 2023).

Bioremediation includes periodic monitoring of the presence and concentration of pollutants in the site where the intervention is in place. This implies that measurable indicator variables related with ecosystem integrity are included, considering that bioremediation indirectly restores contaminated sites. At a long term, the area of ecosystem area restored, and the amount of pollutants reduction could be considered as a target but may lack specific details related to the magnitude of the change to be achieved and the timeframe. Prior to bioremediation, a baseline assessment is conducted, and a monitoring and evaluation system is in place, but may lack detail on the frequency of assessment, the analyses that will be done to determine outcomes, or how information will be shared.

3.3 Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NBS

While there is a general recognition of potential ecosystem-level impacts of bioremediation, especially related to pollutant dispersion (Wang et al., 2021), the evaluation revealed only limited references to Life Cycle Assessment (LCA) plans for mitigating these impacts. However, even though LCA can predict primary impacts caused by site contaminants to users and secondary impacts from remediation operations, several remediation LCA studies have not considered primary impacts on a life cycle basis or factored in social and economic sustainability implications (O'Connor et al., 2019).

3.4 Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NBS strategy

The core of bioremediation lies in implementing measures to reduce pollutants in contaminated sites, which directly impacts ecosystem integrity. Therefore, identifying the requirements for restoring these areas is an integral part of the bioremediation strategy. While certain design characteristics of interventions, such as introducing specific vegetation species, can enhance ecosystem connectivity, it's possible that the primary goal of pollutant removal may conflict with secondary objectives related to biodiversity. Furthermore, it should

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

be noted that bioremediation interventions usually have a specific focus on pollutant removal rather than addressing other aspects related to ecosystem integrity.

Criterion 4. NBS are economically viable

4.1 The direct and indirect benefits and costs associated with the NBS , who pays and who benefits, are identified and documented

There are many forms of bioremediation, each with its specific characteristics regarding implementation and corresponding costs, benefits, and cost-effectiveness. It greatly depends on specific decisions and factors regarding the organism and species used, the severity and type of contamination, the context of the site and the type of soil where the solution is implemented, among other issues.

Various green remediation strategies, such as phytoremediation and soil washing, have been extensively explored in pot, greenhouse and field studies and have already been adopted in some commercial applications, while others such as biochar-based stabilization, citric acid-facilitated low-temperature thermal desorption and bio-electrokinetic remediation have only been investigated on a laboratory scale (Wang et al., 2021).

The phytoremediation system at the site also offers an attractive blend of commercial development and landscape architecture. This not only supports biodiversity but also enhances the visual appeal of the site, providing numerous socioeconomic benefits to its users (O'Connor et al., 2019).

Wan et al., (2016) identifies the costs and benefits of phytoremediation and suggests that the costs are lower compared to other reported values for remediation technologies. Direct economic benefits include an increase in land value after remediation, and indirect benefits, such as employment and local business vitality, should also be taken into account. In terms of costs, the duration of remediation and project risk should be considered (Song et al., 2018). Another dimension to consider is that bioremediation processes are often perceived as project-specific, requiring significant customization, which may not appeal to investors looking for more widely applicable technologies (Ward, 2004).

During the evaluation, information regarding the primary benefits, both direct and indirect, as well as financial and non-financial aspects, was found. However, the identification of costs and benefits and the understanding of their distribution in other bioremediation practices is limited, as they are primarily developed within a research environment.

4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

Phytoremediation of metals is the most effective plant-based approach to remove pollutants from contaminated areas without posing any destructive effects to soil structure (Ashraf et al., 2019). Compared to other remediation methods, phytoremediation is often considered as the option with lower costs but too slow, so developers are inclined to choose remedial strategies with shorter timeframes that allow for quicker returns on investment (Song et al., 2018). Wang et al., (2021), also reflects that although plant-based and microbial-based remediation technologies have a positive environmental impact and extract volatilize or stabilize soil metals effectively, remediation strategies with shorter time frames are often preferred, in order to allow a rapid return on the investment to assure economic sustainability. Therefore, a relevant trade-off between the long-term environmental benefits and the short-term economic benefits should be considered.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Some case studies have reported that, considering the loss caused by environmental pollution, the benefits of phytoremediation will offset the project costs in less than seven years, but this estimation depends on the context of each country and should be precisely calculated in each case (Wan et al., 2016).

During the evaluation, substantial evidence regarding the cost-efficiency of bioremediation was associated with phytoremediation, and no strong evidence of the economic performance of other methods was found (Wan et al., 2016). In this regard, the effectiveness and affordability of phytoremediation and phytomanagement can be broadly justified although there are relevant knowledge gaps.

4.3 The effectiveness of an NBS design is justified against available alternative solutions, taking into account any associated externalities

A wide range of traditional remediation technologies is in use, and new innovative methods are being developed. However, many techniques have significant negative environmental impacts (O'Connor et al., 2019). Traditional soil remediation methods include dig and dump, excavation, soil transport, landfilling, soil washing, the use of oxidants, and incineration and the high cost of these methods has led to the abandonment of numerous contaminated commercial properties rather than their remediation (Megharaj and Naidu, 2017). Furthermore, conventional remediation technologies are associated with environmental risks such as high energy consumption, greenhouse gas emissions, long-term metal leaching risks, and air pollution. They also raise economic concerns, including high capital costs, and social concerns like low public acceptance (Wang et al., 2021).

Phytoremediation offers several benefits over other environmental decontamination methods, including its relatively low cost, in-situ implementation capability, environmental safety, and the potential for using the obtained biomass to extract valuable elements. One of the main drawbacks is the time required for complete soil health recovery (Gorelova and Frontasyeva, 2017; Wan et al., 2016 and Ashraf et al., 2019). Megharaj and Naidu, (2017) and Pandey and Souza-Alonso, (2019) also highlight the benefits and cost-effectiveness of in-situ remediation solutions compared to ex-situ decontamination initiatives.

Nevertheless, while the affordability of bioremediation can be justified, this technology still involves high uncertainties, and there are significant gaps in the analysis that may challenge its cost-effectiveness when compared to other methods in the current context (Wan et al., 2016).

4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

Unlike other industries, the outcomes of bioremediation are not recognised by the market as high-value-added products (Boopathy, 2000). However, new innovative approaches, such as phytomanagement, are offering more attractive investment opportunities for shifting the low investment trend in this technology that has lagged its potential for commercial activity (Wang et al., 2021).

In this regard, from the 2000, in Europe, the financial support has been changed from basic and explorative research to more application-driven research, as shown in several research projects on phytoremediation presently supported by the European Commission 5th Framework Programme and the stronger involvement of small and medium-sized enterprises as partners in the projects presently sponsored, which might reflect a general tendency towards more application-driven research (Schwitzguébel et al., 2002).

The number of academic papers mentioning bioremediation practices, and specifically phytoremediation, has steadily increased since the early 1990s, but the number of patents related to phytoremediation has remained stagnant (Beans, 2017),

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Academic research spurred several phytoremediation-based businesses, but investors have low interest and government funding diminished due to the uncertainties of the technology and the long-term nature of phytoremediation (Beans, 2017). Binding environmental regulations for land use and the land market, with specific targets related to health and safety criteria, could enhance the commercial application of bioremediation and market development (Boopathy, 2000). All over the world, land prices associated with urban areas are continuously increasing, and this could be a motivating force to land developers to remediate contaminated sites under the planning system (Pandey and Souza-Alonso, 2019).

Nevertheless, according to Pandey and Souza-Alonso, (2019) the implementation of phytoremediation on a commercial scale remains disappointing due to time constraints, limited budgets, a general absence of long-term perspectives or proper pollution assessments, together with other factors, such as the lack of social concern and information.

During the review, no strong evidence about the existence of resourcing options secured at a long term that covers the costs of the bioremediation interventions. There is no clear understanding or guarantee of the main long-term funding source beyond that required to cover the costs of immediate start-up or piloting phase.

Criterion 5. NBS are based on inclusive, transparent and empowering governance processes

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention can be initiated

No evidence was found during the evaluation regarding specific feedback and grievance resolution mechanisms developed as part of bioremediation methodologies or interventions in full consultation with affected stakeholders, along with clear evidence of ownership and trust in the mechanism. There is insufficient information to assess whether these mechanisms are legitimate, accessible, predictable, equitable, transparent, rights-compatible, and adaptively managed.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)

During the evaluation, no evidence or information was found regarding how bioremediation initiatives incorporate participation processes based on mutual respect and equality throughout the intervention period. However, Focht et al., (2009) provides a detailed analysis about stakeholder engagement and acceptance of bioremediation technologies that should be considered. The key findings of this study include: the need for more education, distrust issues regarding institutions, a lack of knowledge about bioremediation and a fragile support to these technologies and a preference to empower participation strategies such as independently facilitated deliberation. The study found that the public has significant concerns and distrust related to contamination risks and bioremediation. There is desire more involvement in decision-making and greater transparency.

O'Brien et al., (2021) investigated several projects and found that stakeholder participation was limited in most cases, with little involvement of local community members. Additionally, very few projects used stakeholder mapping and public consultations, and, overall, projects failed to document details about stakeholder engagement.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

Bioremediation typically involves multiple stakeholders, including landowners, bioremediation companies or scientific institutions, public entities, policymakers, and local beneficiaries of the intervention. However, during the review no evidence was found regarding the integration of stakeholder analysis into bioremediation decision-making processes.

5.4 Decision-making processes document and respond to rights and interests of all participating and affected stakeholders

No evidence was found during the evaluation about how decision-making processes take into account rights and interests of the stakeholders and about how the procedures are documented, and this documentation is transparent and accessible.

5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NBS

During the review, no evidence or information was found regarding how bioremediation initiatives establish mechanisms to enable joint decision-making when the scale of the intervention extends beyond jurisdictional boundaries.

Criterion 6. NBS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

The costs and benefits related to trade-offs are acknowledged and consider a significant temporal dimension. The central trade-off concerns the balance between the costs linked to extended bioremediation processes (caused by either low pollutant degradation rates or high initial pollutant concentration levels) and the benefits of attaining a final, lower pollutant concentration level. Corrective actions typically entail prolonging the intervention's maintenance until the desired pollutant concentration levels are reached.

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected

As the LIFE project Biorest defines in its objectives, bioremediation interventions could be used to revegetate the decontaminated soil, restoring its ecological functions and returning it to public use. In this regard, certain rights, land usage, access to land and resources, as well as responsibilities are considered in bioremediation initiatives. However, at a more basic level, bioremediation primarily pertains to the rights associated with land ownership and during the analysis, no strong evidence was found regarding how these rights, land usage, access to land and resources, and stakeholder responsibilities inform the design of interventions.

6.3 Established safeguards are periodically reviewed to ensure that mutually-agreed trade-offs limits are respected and do not destabilise the entire NBS

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Bioremediation interventions aim to decrease the concentration of specific soil pollutants below an agreed-upon limit, and the concentration is periodically reviewed over the course of the intervention timeline.

Criterion 7. NBS are managed adaptively, based on evidence

7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

Bioremediation interventions are based on biological principles related to the removal of pollutants, and the monitoring of pollutant concentrations is guided by the elements that make up the bioremediation strategy. This specifies the expected outcomes regarding pollutant concentration levels, often stipulated by regulations, and outlines how these outcomes will be achieved through the actions taken. This approach is considered during the monitoring and evaluation of the intervention at both the design and implementation stages.

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

Environmental monitoring, soil sampling, measurement protocols, and ex-situ chemical characterization and analysis of toxic components in soil are integrated into bioremediation interventions throughout the entire intervention lifecycle (Gorelova and Frontasyeva, 2017, Henry et al., 2015, Wang et al., 2021). Deviations from the targets typically provide information for management activities related to the maintenance of the bioremediation intervention and the timeframe of the lifecycle.

A successful bioremediation approach requires sufficient evidence of contaminant detoxification and the determination of the reduction of contaminants and their degradation products to regulatory levels through toxicity testing.

The integration of monitoring processes into bioremediation activities is also relevant considering the close relationship between bioremediation and biomonitoring as complementary solutions, ensuring effective contaminant removal while simultaneously assessing the pollutant concentration.

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

It may be reasoned that bioremediation has relatively low adaptability potential, because, like traditional remediation technologies, once the organism that is providing the removal of the pollutant is stablished, they cannot be significantly modified, but, in practice, organisms have some ability to naturally adapt to environmental change (O'Connor et al., 2019).

Some remediation strategies are presented as resilient and adaptative to environmental, social and economic changes and various future site reuse purposes and resist the changing environment (Wang et al., 2021) but during the review no strong evidence was found about a learning framework that is applied at different stages of the intervention lifecycle and linked to the monitoring and evaluation plan.

Criterion 8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

8.1 NBS design, implementation and lessons learnt are shared for triggering transformative change

During the analysis, several pieces of evidence were found regarding the lessons learned and shared, as well as the provisions made to systematize these learnings under different frameworks. However, very limited evidence was found about the communication activities linked with bioremediation interventions.

8.2 NBS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming

During the review, some evidence was found regarding how bioremediation interventions integrate relevant policies, regulations, or laws, especially at a national level. Several EU directives have made soil remediation actions compulsory. The 2004 Environmental Liability Directive obliges companies to remediate contaminated land that poses risks for human health if pollution occurred as the consequence of activities carried out and the 2010 Industrial Emissions Directive requests operators of certain installations to establish the state of soil and groundwater contamination at the start of operations, apply for a permit that includes conditions to prevent soil pollution through application of the best available techniques and to take necessary action upon definitive cessation to return the site to its initial status.

Bioremediation methods weren't however promoted as part of this legislation as solutions to decontaminate sites. They are not mentioned in the texts. The EU Zero Pollution Action Plan does not explicitly refer to bioremediation projects either.

The Soil Monitoring Law, the recent directive proposal, has helped promote bioremediation, including it as a listed recommended risk reduction method, alongside physical and chemical remediation techniques. However, whereas in their initial 2021 Soil Strategy, the Commission had promised that the soil law would require states to "remediate the sites that pose a significant risk to human health and the environment by 2050" Instead, the directive proposal tabled in 2023 sets out that Member States must "carry out a site-specific risk assessment to ascertain whether the contaminated site poses unacceptable risks to human health or the environment and to take the appropriate risk reduction measures". It does not make clean-up operations compulsory, nor fix deadlines.

In this regard, there are gaps that remain, especially concerning binding targets for pollutant concentration levels at the European level and the absence of specific soil laws that support bioremediation interventions, ensuring funding to promote their adoption.

8.3 Where relevant, NBS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

Bioremediation interventions can contribute to achieve the SDG-3 Good Health and Wellbeing and United Nations has set an ambitious sustainable development goal to reduce illnesses and deaths associated with soil contamination by 2030 (Wang et al., 2021). However, while some national and global targets have been identified, the potential contribution of bioremediation to these targets has only been partially defined. During the review, no evidence was found regarding reporting on relevant platforms.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

9.5 Forest diversification

Forest diversification is the practice of managing forests to increase their biodiversity by introducing variability in its composition (multiple species and varieties), structure (mixed tree heights in mixed age stands and heterogeneous arrangement and density of the tree plantation) and genotypic complexity (diverse genetic sources).

Criterion 1: NBS effectively address societal challenges

1.1 The most pressing societal challenges for rights holders and beneficiaries are prioritised

Forest diversification addresses various societal challenges, including wildfire risks, climate change adaptation, and disaster risk reduction. Greater variability in forest structure enhances resilience by reducing rates of fire-induced tree mortality (Koontz et al., 2020). Additionally, practices integrated into forest diversification can contribute to economic development and help combat biodiversity loss (Messier et al., 2022). Rehschuh et al., (2021) also highlights other co-benefits of forest diversification related to land degradation, socioeconomic development, and biodiversity loss.

However, during the evaluation, no evidence was found regarding the prioritization of the most pressing societal challenges based on full consultation with rights holders and beneficiaries.

1.2 The societal challenges addressed are clearly understood and documented

Understanding the drivers of and responses to wildfire risks, as well as their relationship with forest vegetation structure, is generally comprehensive within the relevant context. However, there are still some documentation and knowledge gaps, particularly at the local level and on micro and meso scales. Cartography of forest structure and land use offers detailed documentation for addressing societal challenges at a landscape level (Luhas et al., 2019).

1.3 Human wellbeing outcomes arising from the NBS are identified, benchmarked and periodically assessed

During the review general human well-being outcomes related with wildfire risk reduction, were identified but no provision has been made for their assessment. Diverse planted forests often exhibit similar or higher biomass productivity, are typically less susceptible to biotic and abiotic disturbances, including pest outbreaks and extreme weather events, have greater biodiversity, and offer a broader range of ecosystem functions and services compared to monospecific forests. Additionally, they may enjoy greater social acceptance (Messier et al., 2022). No evidence was found about SMART human well-being outcomes and benchmarks, relevant to the identified societal challenges and national or local context.

Criterion 2. Design of NBS is informed by scale

2.1 Design of NBS recognises and responds to the interactions between the economy, society and ecosystems

Forest diversification recognizes the specific interactions between the economy, society, and ecosystems and incorporates these considerations into its management system. However, during the review, most of the evidence found related to the interactions between ecosystems and the economic performance of the management system from a productive perspective. What is lacking is a comprehensive value chain approach

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

that considers consumer awareness, financial mechanisms, organizational and local territorial approaches, including the relationship of the practice with local cultures, traditions, and identities.

2.2 Design of NBS integrated with other complementary interventions and seeks synergies across sectors

Forest diversification, as a management system that incorporates variability in vegetation structure and composition, intersects with the economic diversification of new wood-based and forest products within the framework of a bioeconomy value chain (Knoke et al., 2017). This approach identifies and explores several synergies across various sectors and integrates complementary interventions into the design of forest diversification management, including construction, energy, chemicals, pulp, paper, and packaging initiatives (Luhas et al., 2019). In this regard, only few synergies across some sectors are broadly identified, but knowledge gaps persist.

2.3 Design of NBS incorporates risk identification and risk management beyond the intervention site

Forest diversification interventions are designed considering economical risks and some environmental risks such as droughts risks and wildfire risks (Brèteau-Amores et al., 2022). Although reasons for the lack of diversification of planted forests are context-specific, Messier et al., (2022) identifies several risks, since diverse forests are more complex operationally to cultivate, manage, and harvest and the public goods produced by more diverse planted forests are not easily marketable.

The conclusions drawn by Roessiger et al., (2011) emphasize that in the presence of risks, the optimal silvicultural strategy does not involve clear-cutting and establishing mono-species forests. Instead, they found that a close-to-nature approach, which combines a high degree of species diversification, maximizes the value at risk. This approach emerges as the optimal choice, particularly for risk-averse forest owners who lack the means to diversify risks through large-scale forest properties.

There are also other studies that collectively suggest that diversification in forest management can help mitigate risks associated with climate change and market uncertainty in the forestry sector. West et al., (2021) found that diversifying forest management regimes in New Zealand can reduce future risks imposed by climate change and market volatility. Knoke et al., (2017) emphasized the role of economic diversification in reducing risks in forest ecosystem management, while other papers provided an overview of risk management in forestry, including biosecurity, fire, wind, climate, and trade risks.

While forest diversification acknowledges various risks, there is a deficiency in the analysis and management of these risks. Specific knowledge gaps in different contexts persist, and there is a shortage of comprehensive documentation.

Criterion 3. NBS result in net gain to biodiversity and ecosystem integrity

3.1 NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

In response to evidence-based assessments, forest diversification can be strategically planned to address specific issues within a forest ecosystem. Information about the current state of ecosystems is available through forest maps detailing forest composition, land uses, and coverage, as well as national forest maps

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

(European Forest Institute, 2023). In forest diversification practices, ecosystem information is generally verified through field visits.

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

Several studies demonstrate the positive impacts of forest diversification on biodiversity. Messier et al., 2022 reveals that monospecific planted forests have lower biodiversity and are potentially more susceptible to disturbances compared to natural or diverse planted forests. In addition, Ampoorter et al., (2020) highlights the role of tree diversity as a key driver of taxon-level and overall forest-associated biodiversity. In this regard, a higher horizontal and vertical heterogeneity in forest structure creates more niche space, refuges, and opportunities for isolation and divergent adaptation, thus facilitating the coexistence of more species (Ampoorter et al., 2020). Duflot et al., (2022) also demonstrates that diversifying forest management through alternative management regimes increases habitat availability for biodiversity indicator species.

Forest diversification has a significant impact on biodiversity and ecosystem integrity, but the specific variables related to these outcomes may lack detailed documentation. While a baseline assessment is conducted before treatments are initiated, the monitoring and evaluation system may not provide specific information regarding the frequency of assessments, the analyses conducted to determine outcomes, or the methods for sharing information.

3.3 Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NBS

During the analysis, no strong evidence was found regarding how monitoring activities are in place to assess adverse consequences on nature arising from forest diversification, especially at the local level. Additionally, there is a lack of information about the effective response actions linked to the results of the monitoring processes aimed at minimizing and mitigating unforeseen risks that could undermine the ecological foundations of forest diversification.

3.4 Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NBS strategy

Forest diversification considers potential options and measures to enhance ecosystem integrity and incorporates them into its strategy. Forest diversification has the potential to boost biodiversity conservation by aligning more closely with the principles of natural ecosystems compared to conventional forestry. Duflot et al., 2022 demonstrated that forest diversification can cost-effectively increase habitat availability and create a heterogeneous mosaic of forest covers, promoting species coexistence at the landscape scale. Further research is needed to determine the scale and locations at which diverse planted forests should be established to maximize landscape-level resilience to global-change threats (Messier et al., 2022).

Criterion 4. NBS are economically viable

4.1 The direct and indirect benefits and costs associated with the NBS , who pays and who benefits, are identified and documented

There are several challenges in the identification and documentation of costs and benefits in forest diversification. During the review, no clear and strong evidence was found regarding the identification and distribution of costs and benefits. Brèteau-Amores et al., (2022) focused on the impact of diversification on

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

drought-induced risk, which indirectly affects the long-term cost and benefit balance. Knoke et al., (2005) also demonstrated how the complex relationship between timber markets, profitability, and the time structure of diversified forest harvests could be beneficial due to risk attenuation.

The European Commission, (2023) identified the economic factors related to Closer-to-Nature Forest management, which is an approach close and, in some elements, like forest diversification. These include economic viability factors, profitability of closer-to-nature forest management, reduced operational costs, biodiversity and resilience, timber production stability and transition considerations.

4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

The cost-effectiveness of forest diversification is recognized, and direct costs and benefits are documented. However, there are notable gaps in accounting for indirect costs and benefits. The long-term economic and financial sustainability is generally understood, but there may be gaps in the consideration of future economic risks related to changes in regulations and subsidy regimes. The review did not find strong evidence indicating a comprehensive understanding of several economic aspects.

4.3 The effectiveness of an NBS design is justified against available alternative solutions, taking into account any associated externalities

Management diversification can yield large gains in multispecies habitat availability with no or low economic cost (Duflot et al., 2022). Messier et al., (2022) shows how monospecific planted forests typically have less potential for providing ecosystem services other than timber or fibre and they often harbour lower associated biological diversity. They are also more susceptible to pests and diseases, saturation or collapse of wood product markets, and climate change when compared to diverse planted forests. The model of large-scale industrial, monospecific planted forests has also been questioned on social grounds since they can lead to an unequal distribution of forest resources and a loss of traditional goods and services used by communities (Messier et al., 2022).

Additionally, diversification increases timber returns and reduces the loss in timber volume due to the drought-induced risk of forest dieback (Brèteau-Amores et al., 2022). In this regard, clear-cutting and mono-species forest stands are not the optimal economic choices in forest stand management, when considered from a risk-avoiding perspective and over a whole rotation (Roessiger et al., 2011).

The effectiveness and affordability of forest diversification can be broadly justified although gaps in the analysis, particularly with respect to a comprehensive understanding of the alternate's cost, benefits and risks, persists. Also, we have to consider that forest diversification can be implemented though several different practices and their diverse economical implication should be considered.

4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

Considering that diversified forestry is a profitable activity, the primary source of long-term funding would be the commercial exploitation of wood products. Additionally, forest diversification offers opportunities to diversify income sources, reducing dependence on volatile wood prices and demand. Non-wood forest products such as honey, mushrooms, and wild game can generate income. The value of ecosystem services, such as water purification, carbon sequestration, and recreational opportunities, is increasingly recognized in monetary terms, and payment-for-ecosystem-services schemes, whether publicly or privately funded, provide additional revenue sources for forest owners and foresters (European Commission, 2023).

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Furthermore, according to European Commission, (2023) various EU funding instruments exist that can support forest diversification. According to the European Commission in 2023, the Common Agricultural Policy (CAP), particularly its rural development program and strategic plans for 2023-2027, supports various specific management commitments and investments. Under the new guidelines for state aid in the agricultural, forestry sectors, and rural areas, Member States can support services related to biodiversity, climate, water, or soil. In addition to granting 100% compensation for additional costs and income foregone by providing these services, it will be possible for forest managers to receive an additional incentive of 20% of the eligible costs for the ecosystem services provided. The EU's LIFE Programme, the European Regional Development Fund (ERDF), and Cohesion Fund provide investments for measures such as these.

During the review, no strong evidence was found regarding how the primary source of long-term funding is identified and secured.

Criterion 5. NBS are based on inclusive, transparent and empowering governance processes

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention can be initiated

No evidence was found during the evaluation regarding specific feedback and grievance resolution mechanisms developed as part of forest diversification methodologies or interventions in full consultation with affected stakeholders, with clear evidence of ownership and trust in the mechanism. There isn't sufficient information to assess whether these mechanisms are legitimate, accessible, predictable, equitable, transparent, rights-compatible, and adaptively managed.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)

There is a long and rich tradition of communities owning, managing, and using forests in Europe, even if these management systems are not necessarily included in forest diversification interventions. Over time, various forms of community-based forestry have evolved in different countries, but all have at their core the concept of involving smallholders and community groups in planning and implementation (Gilmour, 2016). However, the overall diversity of European community forest arrangements has received limited attention in international community forestry literature (Gilmour, 2016).

Furthermore, it is worth noting that there is a significant gap between the strong scientific evidence and the increasing societal support for the multiple benefits and reduced risks of diverse planted forests, and the ongoing dominance of monospecific planted forests (Messier et al., 2022).

Community-managed forests can potentially be more diverse because local communities often comprise a variety of stakeholders with different interests. This diversity can lead to a more balanced approach to forest management that serves multiple purposes beyond timber extraction, based on a deep understanding of their local ecosystems and traditional forest management practices.

However, throughout the analysis, there was a lack of strong evidence or comprehensive information regarding how forest diversification initiatives incorporate participation processes that are based on mutual respect and equality throughout the intervention period.

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

Stakeholder involvement in forest diversification or conservation projects is considered essential for their success and sustainability. Stakeholders may include local communities, government agencies, environmental organizations, private companies. There are several methods for identifying significant actors in close-to nature forestry, and analyse relevant stakeholders (C.J.P., 1995 and Pelyukh et al., 2021). Paletto et al., (2015) and Pelyukh and Paletto, (2019) analyses how stakeholder analysis is a crucial step in the participatory process in order to involve all groups of interests, increasing the legitimacy and transparency of the process in sustainable forest management.

However, during the review no evidence was found regarding the integration of stakeholder analysis into specific forest diversification decision-making processes.

5.4 Decision-making processes document and respond to rights and interests of all participating and affected stakeholders

No evidence was found during the evaluation about how forest diversification decision-making processes take into account rights and interests of the stakeholders and about how the procedures are documented, and this documentation is transparent and accessible.

5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NBS

During the review, no evidence or information was found regarding how forest diversification initiatives establish mechanisms to enable joint decision-making when the scale of the intervention extends beyond jurisdictional boundaries.

Criterion 6. NBS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

Verdone, (2015) presents a cost-benefit framework for accounting for the ecosystem service and economic impacts of forest landscape restoration activities in a way that allows the results to be structured to inform various types of restoration decision-making. This framework can assist decision makers in understanding the trade-offs between different restoration scenarios. The results can serve multiple purposes, including setting prices for payment for ecosystem services, identifying sources of restoration finance, identifying low-cost/high-benefit pathways for carbon sequestration, and determining priority landscapes for restoration through return-on-investment analysis.

Several studies have identified clear trade-offs between biodiversity and the diversification of forest structures and financial returns, but indirect costs related to drought-induced risks may have a negative impact on the total volume of wood in the long term (Brèteau-Amores et al., 2022). Additionally, in general, there are more synergies than trade-offs among different taxa diversities, indicating that changes in forest management could

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

benefit multiple taxa. However, it is important to consider that many other factors can also have an impact (Ampoorter et al., 2020).

Forest diversification, as an economic strategy aimed at developing a broad portfolio of forest-based bioproducts and services linked to multifunctionality, is one of the primary approaches being considered to address the trade-off between economic performance and the positive environmental impact of interventions (Knoke et al., 2017).

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected

The connection between diversifying forests and community-based forestry, as well as other land management approaches like land stewardship, may be considered as a means to acknowledge and respect the rights, utilization, and access to land and resources, in addition to the responsibilities of various stakeholders.

However, our analysis found no evidence of comprehensive assessments within forest diversification interventions, which would include the analysis of all rights, land and resource usage, stakeholder responsibilities, and how the utilization and access to land and resources inform the design of forest diversification.

6.3 Established safeguards are periodically reviewed to ensure that mutually-agreed trade-offs limits are respected and do not destabilise the entire NBS

During the analysis no evidence was found about mutually agreed upon limits of trade-offs and the periodically review of safeguards.

Criterion 7. NBS are managed adaptively, based on evidence

7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

Forest diversification interventions specify the intended outcomes and are based in a clear understanding of how these should be achieved through the actions taken considering the economic, social and ecological conditions. However, during the analysis no strong evidence was found about how this strategy informs monitoring and evaluation processes of forest diversification.

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

Dendrometry, remote sensing, and Geographic Information Systems are often used as tools to monitor and evaluate the current status of forests and the impacts of specific management practices on vegetation structure and diversity. However, the degree of integration of monitoring and evaluation tools depends on the maturity of the forest management system and the specific practices implemented.

While national forest inventories provide information on the state of forests across Europe, including details of their age class distribution, growth rates, and species composition, they offer limited or no details about the management system, forest diversity, harvesting protocols, or patterns of mortality (Larsen et al., 2022).

Approaches such as closer-to-nature forestry practices and adaptive forest management practices are observation-based and involve initiating operations with continuous monitoring of precise indicators. Closer-

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

to-nature forestry allows for adapting operations over time according to ongoing dynamics and unforeseen events (European Commission, 2023).

During the analysis, no strong evidence was found regarding a clear process for how deviations would trigger an adaptive management response in forest diversification initiatives.

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

Forest management often includes learning activities that connect the data collected through monitoring activities, such as dendrometry and remote sensing, with changes in forest management practices. However, the level of integration of adaptive management into forest diversification can vary and depends on the specific intervention. During the analysis, no strong evidence was found regarding how forest diversification incorporates iterative learning. In this context, closer-to-nature forest management appears to be an approach that more explicitly integrates interactive learning, adaptive management, and monitoring activities (European Commission, 2023 and Larsen et al., 2022).

Criterion 8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

8.1 NBS design, implementation and lessons learnt are shared for triggering transformative change

During the review, no compelling evidence was found regarding the systematic gathering and sharing of lessons learned from the design and implementation of forest diversification initiatives.

There is a growing interest in closer-to-nature forest management practices, but the level of experience and interest is not evenly distributed across countries. While several initiatives, such as TreeDivNet, aim to quantify the ecological and social contributions of diverse planted forests to maximize their utility, there is a need for more data and the dissemination of existing information on such diverse planted forests on a global scale (Messier et al., 2022). However, during the analysis, no strong evidence was found regarding the communication strategies in place for forest diversification.

8.2 NBS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming

The CAP provides financial support to rural areas and EU countries can choose to fund forestry interventions through their CAP Strategic Plans. These interventions are aimed at protecting the forest, making it more resilient to climate change, safeguarding its multiple functions, including the provision of environmental services, as well as supporting investments, innovation and training to the benefit of the rural economy. The EAFRD, Pillar II, within the EU's CAP is the most important instrument to support policy objectives which aim at maintaining and sustaining the provision of ecosystems services by forests.

The Forest Strategy also promotes forest diversification at various levels, and the Proposal for a regulation on deforestation-free products, while primarily focused on commercial aspects, may have a positive indirect impact on the adoption of sustainable forest practices. In this context, certain pertinent policies and regulations have been identified as components of the forest diversification design, although their impact on actual implementation is only indirect. These instruments do not directly facilitate the adoption and integration of forest diversification.

Co-funded by the European Union

UK Research and Innovation

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

8.3 Where relevant, NBS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

Forest diversification plays a crucial role in contributing to national and global targets related to human well-being, climate change, biodiversity conservation, and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). Firstly, it promotes human well-being by providing a wide range of ecosystem services such as food, medicines, and clean water, along with recreational opportunities and livelihood support for local communities. Moreover, it contributes to climate change mitigation by sequestering carbon dioxide through the growth of diverse tree species, making forests more resilient to climate change impacts. Forest diversification fosters biodiversity conservation by offering habitats for a diverse array of plant and animal species, which is essential for maintaining healthy ecosystems and protecting endangered species. Lastly, it aligns with the principles of UNDRIP by recognizing the rights of indigenous peoples to manage and control their traditional lands and resources, including forests, thus supporting their cultural, spiritual, and economic needs. Forest diversification can be presented as a comprehensive approach that acknowledges the interconnectedness of environmental, social, and cultural factors in forest management.

However, during the analysis, no strong evidence was found regarding the contribution of forest diversification to relevant national and global targets reported on relevant platforms, even if several forest management initiatives are generally considered as carbon removal initiatives.

9.6 Blue-green infrastructure

Blue-green infrastructures are a strategically planned network of interrelated natural and semi-natural areas with environmental features designed and managed to deliver a wide range of ecosystem services. Green (land) and blue (water) can improve environmental conditions, support green economy and enhance climate change adaptation in cities as they provide evaporative cooling, rainwater infiltration surfaces, wind speed reduction and improve air quality.

Criterion 1: NBS effectively address societal challenges

1.1 The most pressing societal challenges for rights holders and beneficiaries are prioritised

BGI addresses clearly specified challenges that have significant and demonstrable impacts on society. BGI has proved to be an effective solution for improving climate change adaptation and resilience in urban contexts, reducing flood risk (Alves et al., 2020 and Valente De Macedo et al., 2021)

Additionally, BGI provides a wide range of benefits that tackle pressing issues such as temperature increases, poor environmental quality and biodiversity loss, poor urban public spaces and human health. Benefits derived from GBI range from microclimate regulation, pollution reduction and improved air quality, and rainwater drainage to recreational services and noise reduction, from which urban citizens directly benefit (Palliwoda et al., 2022 and Valente De Macedo et al., 2021).

In this sense, Elmqvist et al., (2015) details how BGI provides: 1) microclimate regulation though the implementation of urban parks and vegetation that reduce the urban heat island effect, 2) water regulation though the interception of rainfall by trees and permeable soils in urban areas, 3) pollution reduction and health effects improving air quality although this effect can be context dependent due to the high spatial and temporal

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

variability in and among cities, 3) habitat for a high diversity of plant and animal species and 4) cultural services associated with urban ecosystems.

Participation is one of the main processes in BGI design, and local communities can prioritize the pressing societal challenges when this process is appropriately managed (Wilker et al., 2016).

1.2 The societal challenges addressed are clearly understood and documented

Societal challenges are well understood and documented. The drivers of and responses to climate change, environmental quality, and pollution in relation to human health in urban areas are identified. While there is a broad understanding of these issues, some documentation and knowledge gaps persist at the local level. Specifically, there is a lack of information about how climate change will increase the probability, duration, and severity of specific extreme weather events, such as disasters like floods, at the local level, even though climate projections provide clear information about these trends at regional and global scales.

1.3 Human wellbeing outcomes arising from the NBS are identified, benchmarked and periodically assessed

Specific human well-being outcomes resulting from BGI are identified and assessed. However, the monitoring of these benefits may depend on the specific interventions. Several studies detail how BGI is an important element in cities, contributing to human health, well-being, and the provision of significant ecosystem services and benefits to the urban population (Palliwoda et al., 2022).

BGI contributes to satisfying the needs for outdoor recreation, improving public health, enhancing urban aesthetics and safety, generating green-collar jobs, facilitating urban food security, reducing the costs for housing cooling and providing spaces for social activities, increasing psychological health and stress relief (Andersson et al., 2019; Palliwoda et al., 2022; Dunn, 2010 and Alves et al., 2019). In this regard, access to BGI and green space in cities has been shown to correlate with longevity, post-surgery recovery, reduced stress, mental health, and self-reported perception of health, all of which contribute to higher well-being (Elmqvist et al., 2015).

Criterion 2. Design of NBS is informed by scale

2.1 Design of NBS recognises and responds to the interactions between the economy, society and ecosystems

The design of BGI recognises specific interactions between the economy, society and ecosystems. These interactions are usually mapped as part of the urban planning and land-use management activities that are carried out by the responsible institutions.

In this regard, ecosystem services, as the relationships between people, such as climate regulation to in-situ appreciation of nature's aesthetic, are already widely considered in BGI planning (Langemeyer and Baró, 2021). The network nature of BGI is linked with the recognition of the complexity of urban systems and though different disciplines, such as GIS Analysis, BGI acknowledges and address interactions between economy, society and ecosystems to build them into the decision-making process (Langemeyer and Baró, 2021).

BGI include interactions beyond the intervention area and puts explicit emphasis on scale issues and on the functional connection and interrelation of green and blue spaces within and adjacent to cities (Andersson et al., 2019 and Langemeyer and Baró, 2021). However, during the analysis no strong evidence was found about how these interactions are considered over time.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

2.2 Design of NBS integrated with other complementary interventions and seeks synergies across sectors

BGI design includes the identification of existing natural and semi-natural areas and interventions that provide specific ecosystem services and its integrated in a network. Synergies across sectors are considered to design the concrete interventions that are part of the BGI. These sectors may include green areas management, blue areas management, urban planning and design, transportation, water management, environmental and conservation organizations, local government, community and public engagement, research and education and construction and engineering. In this regard, BGI systematically and strategically deploy natural elements, including greenspaces and water bodies within the urban environment, having as core principles connectivity and multi-functionality to promote ecosystem services and enhance climate resiliency (Valente De Macedo et al., 2021). Andersson et al., (2019) also discuss about how GBI as a network is integrated and connected with other urban infrastructures.

2.3 Design of NBS incorporates risk identification and risk management beyond the intervention site

Several potential risks have been identified and considered in the design of the BGI, but there are still context-specific knowledge gaps, and documentation is lacking. Risks associated with blue-green infrastructure include design and implementation risks, environmental impacts, inadequate maintenance, long-term sustainability, public perception and acceptance, hydrological risks and climate risks, legal and regulatory risks, financial and budgetary issues, health and safety risks, and the potential for property devaluation.

A holistic approach to urban planning also requires considering their potential disservices, such as the proliferation of infectious disease vectors and safety risks. Additionally, in some contexts, urban populations perceive the proximity to parks or forested areas as a safety risk due to physical injuries, exposure to wild animals, or criminal attacks. (Valente De Macedo et al., 2021). Since BGI interventions are closely related to climate change adaptation processes and initiatives that are usually aligned with project management standards, risks are one of the aspects commonly controlled with these interventions.

However, during the analysis, no strong evidence was found regarding the comprehensive identification of most risks associated with undesirable changes and their underlying factors. This includes the consideration of both scientific and local knowledge and the integration of risk management strategies into the design of BGI, with periodic reviews throughout the intervention timeline.

Criterion 3. NBS result in net gain to biodiversity and ecosystem integrity

3.1 NBS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss

Geographical Information Systems (GIS) are essential tools in spatial planning and urban environmental management. Specifically, BGI usually follows methodologies that encompass an assessment of the current ecological conditions within the intervention area, including a SWOT analysis of the environment. Nevertheless, various challenges are associated with acquiring and utilizing suitable and pertinent data for BGI planning in urban settings. These challenges are interconnected with economic, social, and environmental technical factors and encompass issues such as insufficient information regarding the present ecosystem state and the underlying drivers of degradation and loss (Sörensen et al., 2021).

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically assessed

BGI has positive outcomes related to biodiversity and ecosystem integrity, and in some cases, these outcomes are monitored. Filazzola et al., (2019) examined 1,883 published manuscripts and conducted a meta-analysis of 33 studies, determining that BGI enhances biodiversity by providing a more suitable habitat for species compared to conventional, impervious grey infrastructure.

3.3 Monitoring includes periodic assessments for unintended adverse consequences on nature arising from the NBS

Some potential adverse consequences for nature resulting from possible risks are identified and considered during the design of the BGI. However, there are still knowledge gaps specific to the context, and there is a lack of comprehensive documentation. The analysis did not uncover strong evidence of periodic assessments of potential negative impacts in the monitoring process, even though general identification is typically integrated into BGI initiatives and specific measures for mitigating these impacts are implemented.

3.4 Opportunities to enhance ecosystem integrity and connectivity identified and incorporated into the NBS strategy

The BGI approach involves the systematic and strategic deployment of natural elements within the urban environment, with core principles centered on connectivity and multi-functionality to promote ecosystem services and enhance climate resilience (Valente De Macedo et al., 2021). In this regard connectivity is a key concept for BGI, since many of the bene fits of BGI can only be truly realized by an inter connected network of its constituting components (Ghofrani et al., 2017 and Elmqvist et al., 2015). For example, a systematically planned BGI could increase the connectivity of protected areas and Natura 2000 sites, to allow species to thrive across their entire natural habitat and adapt to effects of climate change, improving the coverage of species of EU-conservation interest beyond current protected areas (Hermoso et al., 2020). In general terms, cross-scale connectivity in GBI planning is critical, as many benefits provided or obtained from ecosystems align when individual ecosystems are interconnected (Langemeyer and Baró, 2021).

Criterion 4. NBS are economically viable

4.1 The direct and indirect benefits and costs associated with the NBS , who pays and who benefits, are identified and documented

During the bibliographic review only, some evidence was found about how BGI integrates an analysis of costs and benefits that include both financial and non-financial elements with a general understanding of how the major costs and benefits are distributed. The identification of costs and benefits is limited solely to the immediate and direct financial transactions of the initiative. Understanding how these costs and benefits are distributed is not defined in detail due to the extensive range and complexity of the benefits that GBI provides. It must be taken into account that there are various factors to consider in this regard. There are specific uncertainties associated with the long-term sustainability of BGI and the maintenance costs required to ensure that the projected benefits are realized over the lifetime of the installations. (Lamond and Everett, 2019). Moreover, decision-making processes have traditionally focused on benefits associated with flood risk reduction. Alves et al., (2019) provides a method to include the monetary analysis of BGI co-benefits into a cost-benefits analysis of flood risk mitigation measures. However BGI also presents a wide range of co-

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

benefits, such as water savings, reduced energy consumption for cooling, improved air quality, and carbon sequestration, all of which should be considered in the cost benefit analysis (Alves et al., 2019).

Elmqvist et al., (2015) argue that many benefits produced by BGI cannot be readily or adequately captured by monetary metrics, such as health, aesthetics, enhanced social cohesion and trust, and other values related with sense of identity. Many of these non-monetary benefits remain unmapped and unmeasured, especially those related to physical and psychological health. However, according to Elmqvist et al., 2015, investments in enhancing BGI are ecologically and socially required, but also economically viable.

4.2 A cost-effectiveness study is provided to support the choice of NBS including the likely impact of any relevant regulations and subsidies

During the evaluation, no strong evidence was found regarding the cost-effectiveness of BGI, and no information was identified about the calculation of a basic internal rate of return that takes into account direct upfront and recurring costs and benefits. The long-term economic and financial sustainability of BGI is broadly understood, but there may be gaps in framing future economic risks related to changes in regulation and subsidy regimes, given that BGIs are primarily funded by local public administrations.

Although some non-monetary benefits have been identified, it should be noted that quantifying the effectiveness of BGI could be highly complex due to the diverse nature of their positive impacts and the lack of precise modelling tools to estimate how BGI specifically addresses societal challenges.

4.3 The effectiveness of an NBS design is justified against available alternative solutions, taking into account any associated externalities

Grey solutions that involve traditional or conventional technologies and practices are considered as the main alternative to BGI. BGI effectiveness has been justified although gaps in the analysis, particularly with respect to a comprehensive understanding of the alternate's cost, benefits and risks, persists.

In this regard, grey measures appear as feasible if co-benefit are not taken into account. However, when secondary benefits are included, combinations of green-grey measures and green-blue-grey measures

appear as economically viable and, at the same time, good to ensure the primary benefit of flood risk reduction (Alves et al., 2019).

The viability of green and blue infrastructure for flood mitigation can be improved substantially when co-benefits are considered. In the case analysed in Alves et al., (2019) traditional grey option appears as the only economically viable strategy if co-benefits are not considered. Thus, it is important to assess co-benefits when identifying best adaptation strategies to improve urban flood risk management, otherwise green infrastructure is likely to appear less efficient than conventional grey infrastructure.

4.4 NBS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance

BGI design considers a portfolio of resourcing options to support its development, although further analysis is required to properly assess feasibility. A combination of funding sources can be used to create and maintain blue-green infrastructure projects effectively from a blended finance perspective. These sources are: 1) market-based financing from the private sector, such as businesses, investors, and financial institutions, which can be mobilized through public-private partnerships, 2) public sector funding from government agencies at various levels, including local, regional, national, and supranational entities, including budget allocations,

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

grants, and subsidies, 3) voluntary commitments from organizations, communities, and individuals who are interested in advancing sustainability and green practices and 4) actions to support regulatory compliance, particularly in areas related to environmental protection, water management, and sustainability.

However, during the review, no strong evidence was found regarding how the principal source of long-term funding is secured.

Criterion 5. NBS are based on inclusive, transparent and empowering governance processes

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NBS intervention can be initiated

No evidence was found during the evaluation regarding specific feedback and grievance resolution mechanisms developed as part of BGI methodologies or interventions in full consultation with affected stakeholders, with clear evidence of ownership and trust in the mechanism. There isn't sufficient information to assess whether these mechanisms are legitimate, accessible, predictable, equitable, transparent, rights-compatible, and adaptively managed. However, there are feedback and grievance resolution mechanisms in place as general tools for public participation at various institutional levels, specifically at the local level where BGI initiatives are usually developed, and which is closer to citizen and stakeholder participation.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free Prior and Informed Consent (FPIC)

Community engagement has been identified as critical for the successful implementation of BGI. Local stewardship and participation are often integrated into BGI interventions as a means of involving local publics in management to support long-term maintenance (Lamond and Everett, 2019). Wilker et al., (2016) investigated participation approaches of six green infrastructure investments and found that stakeholders were generally satisfied with how they were involved but desired a broader and more tailored mix of approaches. Ferreira et al., (2020) also recognises the relevance of different stakeholder engagement processes in BGI initiatives.

On the other hand, many guidelines frame communities as passive users and do not consider power relations framing and engagement (Everett et al., 2023). In this regard Everett et al., (2023) proposes a set of principles for the development of community engagement frameworks to facilitate and encourage greater community co-production of BGI.

BGI initiatives tend to include participation processes, involving active collaboration with local communities and stakeholders in the planning, design, and decision-making related to the infrastructure but participation could be higher and there is a lack of processes in place to ensure this persists throughout the intervention.

5.3 Stakeholders who are directly and indirectly affected by the NBS have been identified and involved in all processes of the NBS intervention

Stakeholder analysis is increasingly recognized in the context of BGI, but research and practical implementation in several related domains are still lacking (Ferreira et al., 2020)

5.4 Decision-making processes document and respond to rights and interests of all participating and affected stakeholders

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

BGI decision-making processes may address the rights and interests of certain stakeholders. Considering that they are typically publicly funded by municipal and regional institutions. BGI projects often adhere to documentation management standards, which include criteria for transparency and accessibility. However, no strong evidence was found during the evaluation regarding how BGI decision-making processes systematically consider the rights and interests of stakeholders or how the procedures are documented and whether this documentation is transparent and accessible.

5.5 Where the scale of the NBS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making among the stakeholders in those jurisdictions affected by the NBS

BGI functions across jurisdictional boundaries, and its planning can be considered at multiple scales and contexts, including urban, peri-urban, regional, and site levels (Ghofrani et al., 2017 and Allen, 2012). When necessary, certain transboundary cooperation agreements are established between affected stakeholders in various jurisdictions, although gaps persist. For example, challenges may arise when connecting local BGI with regional-level and microscale initiatives.

Criterion 6. NBS equitably balances trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits

6.1 The potential costs and benefits of associated trade-offs of the NBS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions

Despite the popularity and desirability of so-called win–win solutions in urban spatial planning, they appear to be rare in real-world situations, where managers often must contend with trade-offs among different benefits obtained from BGI (Turkelboom et al., 2018). For instance, when prioritizing flood risk reduction other co-benefits are significantly diminished and on the other hand, when we introduce the enhancement of co-benefits, the effectiveness of flood mitigation may be compromised (Alves et al., 2020).

The distributional effects of BGI may not be immediately apparent in terms of both space and time (Andersson et al., 2019). Addressing trade-offs between ecosystem services or the interests of different beneficiaries often necessitates consideration on larger temporal and spatial scales. Additionally, examples such as green gentrification illustrate how the implementation of new urban BGI can alter access to benefits by reshaping neighbourhood demographics. Consequently, this can lead to unjust outcomes in the medium or long term, including the displacement of the most vulnerable (Andersson et al., 2019). In this sense, Turkelboom et al., (2018) offers an in-depth analysis of ecosystem services trade-offs within spatial planning.

Additionally, ES relationships and trade-offs at various scales are already a relevant issue in GBI planning due to competitive land uses, such as recreation and biodiversity protection (Langemeyer and Baró, 2021). Aligning and implementing BGI across multiple scales is crucial for enhancing interscale collaboration and overcoming traditional barriers in ES provision, ensuring that benefits flow without obstacles (Langemeyer and Baró, 2021).

In conclusion, while trade-offs are often identified, during the review, no evidence was found of explicit acknowledgment of their associated costs and benefits.

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders are acknowledged and respected

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

The institutional context, including sectoral, jurisdictional, and administrative divisions, often serves as the foundation for GBI management. Land-use planning and property laws influence who can access specific benefits and contribute to GBI development (Andersson et al., 2019).

There are documented issues related to the distribution and accessibility of both GBI and its benefits, and the unequal distribution of benefits has significant implications for those who have access to different ecosystem services. The ongoing discussion on equitable ES delivery takes into account various factors, including urban development pathways, institutional arrangements (such as property rights and governance schemes), power dynamics, procedural justice, and historical legacies of social inequity (Andersson et al., 2019).

Additionally, the implementation of BGI can transform community land into aesthetically controlled and organized natural spaces, primarily catering to the middle and upper classes and tourists. This transformation is associated with gentrification, real estate speculation, and the displacement of resident communities (Anguelovski et al., 2019).

In this context, considering the underlying structural causes of vulnerability and the need for green urban spaces to mitigate specific societal challenges, it can be argued that certain rights, land and resource usage, access, as well as responsibilities, should be analysed, acknowledged, and respected.

6.3 Established safeguards are periodically reviewed to ensure that mutually agreed trade-offs limits are respected and do not destabilise the entire NBS

Turkelboom et al., (2018), provide a comprehensive analysis of ecosystem services trade-offs in spatial planning and the responses being implemented. Although only some of these responses are integrated into BGI interventions, risks and potential adverse consequences are typically considered in the design of specific measures within BGI.

The responses to the trade-offs depend on the stakeholder's influence in BGI design and implementation, and they can be categorized into three types: communication and negotiation, problem-solving strategies to modify ecosystem use, and investment in new knowledge (Turkelboom et al., 2018).

However, no strong evidence was found during the review regarding the implementation and documentation of safeguards, specifically in terms of measures to anticipate and prevent adverse consequences of interventions.

Criterion 7. NBS are managed adaptively, based on evidence

7.1 A NBS strategy is established and used as a basis for regular monitoring and evaluation of the intervention

BGI interventions specify the intended outcomes and are based in a clear understanding of how these should be achieved through the actions taken considering the economic, social and ecological conditions. The monitoring and evaluation plan is linked with and describes what the BGI did, how it functions, and why the monitoring outcomes are significant (Geberemariam, 2016).

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

During the review it was found that several monitoring and evaluation activities are integrated as part of BGI interventions and several studies gather and propose monitoring and assessment methodologies for green infrastructure initiatives. Pakzad et al., (2017) propose frameworks and indicators for assessing the performance and sustainability of green infrastructure projects. Furberg et al., (2020) and Taramelli et al., (2019) consider how remote sensing and GIS Analysis remote sensing could be used to monitor BGI. These papers highlight the importance of regular monitoring and assessment to ensure the effectiveness and sustainability of green infrastructure projects.

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle

During the review, no strong evidence was found regarding how BGI integrates learning activities that connect the data gathered in monitoring with the implemented measures. However, since BGI is closely linked to the climate adaptation and resilience framework, some general principles of adaptive management are considered in certain interventions (Ghofrani et al., 2017).

Criterion 8. NBS are sustainable and mainstreamed within an appropriate jurisdictional context

8.1 NBS design, implementation and lessons learnt are shared for triggering transformative change

BGI interventions acknowledge that communication is a valuable approach to induce changes in behaviour among stakeholders and citizens, with the goal of encouraging communities to appreciate and value BGI (Lamond and Everett, 2019). Lessons learned from BGI initiatives have been documented and shared through various platforms, including databases, interactive maps of BGI success stories and pilot cases, communication toolkits, methodological support guidelines, and other resources gathered in initiatives like the Network Nature project. Additionally, several reports, such as Kazmierczak and Carter, (2010) and Scott et al., (2023), contribute to this knowledge sharing.

8.2 NBS inform and enhance facilitating policy and regulation frameworks to support its uptake and mainstreaming

Similar to other NBS, green and blue infrastructure has been mentioned in several of the European Commission's policy mechanisms. In 2013, the European Commission published the European Green Infrastructure Strategy, Enhancing Europe's Natural Capital, for the conservation and restoration of ecosystem services (Langemeyer and Baró, 2021).

In the Commission's proposals for the Cohesion Fund and the European Regional Development Fund (ERDF), Green Infrastructure is specifically listed as an investment priority (Langemeyer and Baró, 2021). Other mechanisms like the European Agricultural Fund for Rural Development and the European Fund for Strategic Investment could also support BGI.

Given the importance of agricultural and forestry areas in BGI, these funding programs will play a key role in financing and ensuring the implementation of the GI network. For instance, the Common Agricultural Policy also contributes significantly to funding and ensuring the success of these initiatives through the designation of Ecological Focus Areas (Hermoso et al., 2020).

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Both the 2020 Biodiversity Strategy and the 2021 Soil Strategy mention the goal of achieving No Net Land Take by 2050. The 2022 Nature Restoration Regulation Proposal took a step further by proposing specific requirements for urban surfaces. However, this proposal was only adopted by the European Parliament in and it remains to be seen whether the European Council will accept it and how it will be implemented by each Member State. The targets include achieving no net loss in the total national area of urban green space and urban tree canopy cover in urban ecosystem areas by 2030, except in cities which have already invested in green infrastructure by 2030, a gradual increase in the total national area of urban green spaces and a gradual increase in the total in urban tree canopy cover

Finally, in addition, the New European Bauhaus, also supports many green or blue infrastructure projects across Europe and integrate innovative design and sustainable practices into urban planning.

However, further policy development will be necessary to ensure that these worklines are effectively developed and utilized to implement and manage BGI (Hermoso et al., 2020).

8.3 Where relevant, NBS contribute to national and global targets for human wellbeing, climate change, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

GBI strategies are recognized as a way of meeting several of the SDGs, such as health (SDG 3), clean water and sanitation (SDG 6); innovation and infrastructure (SDG 9), sustainable cities (SDG 11) and environmental protection (SDGs 13, 14 and 15) (Valente De Macedo et al., 2021). BGI also contributes to Target 2 of the Biodiversity Strategy, including the restoration of degraded habitats and the No-Net-Loss principle. Various European awards and initiatives promote green and blue infrastructure. The European Commission hosts awards like European Green Capitals and Green Leafs, recognizing cities committed to urban sustainability and green space development. In addition, the European Commission's Green City Accord encourages European mayors to support green infrastructure projects, fostering a growing movement among city leaders.

10 References

Abad, J., Hermoso De Mendoza, I., Marín, D., Orcaray, L., Santesteban, L.G., 2021. Cover crops in viticulture. A systematic review (1): Implications on soil characteristics and biodiversity in vineyard. OENO One 55, 295–312. https://doi.org/10.20870/oeno-one.2021.55.1.3599

Adil, A., Syarief, R., Widiatmaka, Najib, M., 2022. Stakeholder Analysis and Prioritization of Sustainable Organic Farming Management: A Case Study of Bogor, Indonesia. Sustainability 14, 16706. https://doi.org/10.3390/su142416706

Allen, W.L., 2012. Environmental Reviews and Case Studies: Advancing Green Infrastructure at All Scales: From Landscape to Site. Environmental Practice 14, 17–25. https://doi.org/10.1017/S1466046611000469

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., Sanchez, A., 2019. Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management. Journal of Environmental Management 239, 244–254. https://doi.org/10.1016/j.jenvman.2019.03.036

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Alves, A., Vojinovic, Z., Kapelan, Z., Sanchez, A., Gersonius, B., 2020. Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation. Science of The Total Environment 703, 134980. https://doi.org/10.1016/j.scitotenv.2019.134980

Ampoorter, E., Barbaro, L., Jactel, H., Baeten, L., Boberg, J., Carnol, M., Castagneyrol, B., Charbonnier, Y., Dawud, S.M., Deconchat, M., Smedt, P.D., Wandeler, H.D., Guyot, V., Hättenschwiler, S., Joly, F., Koricheva, J., Milligan, H., Muys, B., Nguyen, D., Ratcliffe, S., Raulund-Rasmussen, K., Scherer-Lorenzen, M., Van Der Plas, F., Keer, J.V., Verheyen, K., Vesterdal, L., Allan, E., 2020. Tree diversity is key for promoting the diversity and abundance of forest-associated taxa in Europe. Oikos 129, 133–146. https://doi.org/10.1111/oik.06290

Andersson, E., Langemeyer, J., Borgström, S., McPhearson, T., Haase, D., Kronenberg, J., Barton, D.N., Davis, M., Naumann, S., Röschel, L., Baró, F., 2019. Enabling Green and Blue Infrastructure to Improve Contributions to Human Well-Being and Equity in Urban Systems. BioScience 69, 566–574. https://doi.org/10.1093/biosci/biz058

Angouria-Tsorochidou, E., Teigiserova, D.A., Thomsen, M., 2021. Limits to circular bioeconomy in the transition towards decentralized biowaste management systems. Resources, Conservation and Recycling 164, 105207. https://doi.org/10.1016/j.resconrec.2020.105207

Anguelovski, I., Irazábal-Zurita, C., Connolly, J.J.T., 2019. Grabbed Urban Landscapes: Socio-spatial Tensions in Green Infrastructure Planning in Medellín. Int J Urban Regional Res 43, 133–156. https://doi.org/10.1111/1468-2427.12725

Ashraf, Sana, Ali, Q., Zahir, Z.A., Ashraf, Sobia, Asghar, H.N., 2019. Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. Ecotoxicol Environ Saf 174, 714–727. https://doi.org/10.1016/j.ecoenv.2019.02.068

Askarany, D., Franklin-Smith, A.W., 2014. Cost Benefit Analyses of Organic Waste Composting Systems through the Lens of Time Driven Activity-Based Costing. Journal of Applied Management Accounting Research, The University of Auckland Business School Research Paper, 12, 59–73.

Barra Caracciolo, A., Grenni, P., Garbini, G.L., Rolando, L., Campanale, C., Aimola, G., Fernandez-Lopez, M., Fernandez-Gonzalez, A.J., Villadas, P.J., Ancona, V., 2020. Characterization of the Belowground Microbial Community in a Poplar-Phytoremediation Strategy of a Multi-Contaminated Soil. Frontiers in Microbiology 11.

Beans, C., 2017. Phytoremediation advances in the lab but lags in the field. Proc. Natl. Acad. Sci. U.S.A. 114, 7475–7477. https://doi.org/10.1073/pnas.1707883114

Bengtsson, J., Ahnström, J., Weibull, A.-C., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis: Organic agriculture, biodiversity and abundance. Journal of Applied Ecology 42, 261–269. https://doi.org/10.1111/j.1365-2664.2005.01005.x

Beniaich, A., Guimarães, D.V., Avanzi, J.C., Silva, B.M., Acuña-Guzman, S.F., Dos Santos, W.P., Silva, M.L.N., 2023. Spontaneous vegetation as an alternative to cover crops in olive orchards reduces water erosion and improves soil physical properties under tropical conditions. Agricultural Water Management 279, 108186. https://doi.org/10.1016/j.agwat.2023.108186

Bergtold, J.S., Ramsey, S., Maddy, L., Williams, J.R., 2019. A review of economic considerations for cover crops as a conservation practice. Renew. Agric. Food Syst. 34, 62–76. https://doi.org/10.1017/S1742170517000278

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Birkhofer, K., Bezemer, T.M., Bloem, J., Bonkowski, M., Christensen, S., Dubois, D., Ekelund, F., Fließbach, A., Gunst, L., Hedlund, K., Mäder, P., Mikola, J., Robin, C., Setälä, H., Tatin-Froux, F., Van Der Putten, W.H.,

Boopathy, R., 2000. Factors limiting bioremediation technologies. Bioresource Technology 74, 63–67. https://doi.org/10.1016/S0960-8524(99)00144-3

Bos, J.F.F.P., Ten Berge, H.F.M., Verhagen, J., Van Ittersum, M.K., 2017. Trade-offs in soil fertility management on arable farms. Agricultural Systems 157, 292–302. https://doi.org/10.1016/j.agsy.2016.09.013

Brèteau-Amores, S., Fortin, M., Andrés-Domenech, P., Bréda, N., 2022. Is Diversification a Suitable Option to Reduce Drought-Induced Risk of Forest Dieback? An Economic Approach Focused on Carbon Accounting. Environ Model Assess 27, 295–309. https://doi.org/10.1007/s10666-022-09821-w

Budiman, I., Bastoni, Sari, E.N., Hadi, E.E., Asmaliyah, Siahaan, H., Januar, R., Hapsari, R.D., 2020. Progress of paludiculture projects in supporting peatland ecosystem restoration in Indonesia. Global Ecology and Conservation 23, e01084. https://doi.org/10.1016/j.gecco.2020.e01084

Budiman, I., Hapsari, R.D., Wijaya, C.I., Sari, E.N.N., 2021. The Governance of Risk Management on Peatland: A Case Study of Restoration in South Sumatra, Indonesia. WRIPUB. https://doi.org/10.46830/wriwp.20.00008

Bugnot, A.B., Dafforn, K.A., Erickson, K., McGrath, A., O'Connor, W.A., Gribben, P.E., 2023. Reintroducing a keystone bioturbator can facilitate microbial bioremediation in urban polluted sediments. Environmental Pollution 324, 121419. https://doi.org/10.1016/j.envpol.2023.121419

Cecchin, A., Pourhashem, G., Gesch, R.W., Lenssen, A.W., Mohammed, Y.A., Patel, S., Berti, M.T., 2021. Environmental trade-offs of relay-cropping winter cover crops with soybean in a maize-soybean cropping system. Agricultural Systems 189, 103062. https://doi.org/10.1016/j.agsy.2021.103062

Chojnacka, K., Moustakas, K., Witek-Krowiak, A., 2020. Bio-based fertilizers: A practical approach towards circular economy. Bioresource Technology 295, 122223. https://doi.org/10.1016/j.biortech.2019.122223

C.J.P., C., 1995. Who counts most in sustainable forest management? Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/000067

Crowder, D.W., Reganold, J.P., 2015. Financial competitiveness of organic agriculture on a global scale. Proc. Natl. Acad. Sci. U.S.A. 112, 7611–7616. https://doi.org/10.1073/pnas.1423674112

Daadi, B.E., Latacz-Lohmann, U., 2021. Assessing farmers' attitudes to, and the behavioural costs of, organic fertiliser practices in northern Ghana: An application of the behavioural cost approach. Heliyon 7, e07312. https://doi.org/10.1016/j.heliyon.2021.e07312

Daryanto, S., Fu, B., Wang, L., Jacinthe, P.-A., Zhao, W., 2018. Quantitative synthesis on the ecosystem services of cover crops. Earth-Science Reviews 185, 357–373. https://doi.org/10.1016/j.earscirev.2018.06.013

Duflot, R., Eyvindson, K., Mönkkönen, M., 2022. Management diversification increases habitat availability for multiple biodiversity indicator species in production forests. Landsc Ecol 37, 443–459. https://doi.org/10.1007/s10980-021-01375-8

Dunn, A.D., 2010. Siting Green Infrastructure: Legal and Policy Solutions to Alleviate Urban Poverty and Promote Healthy Communities. Boston College Environmental Affairs Law Review 37.

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Dvořák, P., Nikel, P.I., Damborský, J., de Lorenzo, V., 2017. Bioremediation 3.0: Engineering pollutant-removing bacteria in the times of systemic biology. Biotechnology Advances 35, 845–866. https://doi.org/10.1016/j.biotechadv.2017.08.001

Elmqvist, T., Setälä, H., Handel, S., Van Der Ploeg, S., Aronson, J., Blignaut, J., Gómez-Baggethun, E., Nowak, D., Kronenberg, J., De Groot, R., 2015. Benefits of restoring ecosystem services in urban areas. Current Opinion in Environmental Sustainability 14, 101–108. https://doi.org/10.1016/j.cosust.2015.05.001

European Commission, 2023a. Proposal for a Directive of the European Parliament and of the Council on Soil Monitoring and Resilience (Soil Monitoring Law). COM 416 final 2023/0232 (COD).

European Commission, 2023b. Guidelines on Closer-to-Nature Forest Management.

European Commission, 2018. Circular Economy: Agreement on Commission proposal to boost the use of organic and waste-based fertilisers. URL https://ec.europa.eu/commission/presscorner/detail/en/IP_18_6161

EUROSTAT, 2023a. Circular economy Monitoring framework. URL https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework

EUROSTAT, 2023b. Agri-environmental indicators (AEIs) - Agriculture - Eurostat [WWW Document]. URL https://ec.europa.eu/eurostat/web/agriculture/agri-environmental-indicators

Everett, G., Adekola, O., Lamond, J., 2023. Developing a blue-green infrastructure (BGI) community engagement framework template. Urban Des Int 28, 172–188. https://doi.org/10.1057/s41289-021-00167-5

Fan, Y., Liu, Y., DeLaune, P.B., Mubvumba, P., Park, S.C., Bevers, S.J., 2020. Economic analysis of adopting no-till and cover crops in irrigated cotton production under risk. Agronomy Journal 112, 395–405. https://doi.org/10.1002/agj2.20005

Fendrich, A.N., Matthews, F., Van Eynde, E., Carozzi, M., Li, Z., d'Andrimont, R., Lugato, E., Martin, P., Ciais, P., Panagos, P., 2023. From regional to parcel scale: A high-resolution map of cover crops across Europe combining satellite data with statistical surveys. Science of The Total Environment 873, 162300. https://doi.org/10.1016/j.scitotenv.2023.162300

Ferreira, V., Barreira, A., Loures, L., Antunes, D., Panagopoulos, T., 2020. Stakeholders' Engagement on Nature-Based Solutions: A Systematic Literature Review. Sustainability 12, 640. https://doi.org/10.3390/su12020640

Filazzola, A., Shrestha, N., MacIvor, J.S., 2019. The contribution of constructed green infrastructure to urban biodiversity: A synthesis and meta-analysis. Journal of Applied Ecology 56, 2131–2143. https://doi.org/10.1111/1365-2664.13475

Focht, W., Albright, M., Anex, Robert P., Jr., Ed., 2009. ENHANCING STAKEHOLDER ACCEPTANCE OF BIOREMEDIATION TECHNOLOGIES (No. DOE/ER/63798-1, 951591). https://doi.org/10.2172/951591

Furberg, D., Ban, Y., Mörtberg, U., 2020. Monitoring Urban Green Infrastructure Changes and Impact on Habitat Connectivity Using High-Resolution Satellite Data. Remote Sensing 12, 3072. https://doi.org/10.3390/rs12183072

Geberemariam, T., 2016. Post Construction Green Infrastructure Performance Monitoring Parameters and Their Functional Components. Environments 4, 2. https://doi.org/10.3390/environments4010002

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Ghofrani, Z., Sposito, V., Faggian, R., 2017. A Comprehensive Review of Blue-Green Infrastructure Concepts. International Journal of Environment and Sustainability 6. https://doi.org/10.24102/ijes.v6i1.728

Gilmour, D., 2016. Forty years of community-based forestry. A review of its extent and effectiveness. FAO Forestry Paper 2016 No.176, pp.140.

Gómez-Sagasti, M.T., Garbisu, C., Urra, J., Míguez, F., Artetxe, U., Hernández, A., Vilela, J., Alkorta, I., Becerril, J.M., 2021. Mycorrhizal-Assisted Phytoremediation and Intercropping Strategies Improved the Health of Contaminated Soil in a Peri-Urban Area. Front. Plant Sci. 12, 693044. https://doi.org/10.3389/fpls.2021.693044

Gorelova, S.V., Frontasyeva, M.V., 2017. The Use of Higher Plants in Biomonitoring and Environmental Bioremediation, in: Ansari, A.A., Gill, S.S., Gill, R., R. Lanza, G., Newman, L. (Eds.), Phytoremediation. Springer International Publishing, Cham, pp. 103–155. https://doi.org/10.1007/978-3-319-52381-1_5

Henry, H., Naujokas, M.F., Attanayake, C., Basta, N.T., Cheng, Z., Hettiarachchi, G.M., Maddaloni, M., Schadt, C., Scheckel, K.G., 2015. Bioavailability-Based In Situ Remediation To Meet Future Lead (Pb) Standards in Urban Soils and Gardens. Environ. Sci. Technol. 49, 8948–8958. https://doi.org/10.1021/acs.est.5b01693

Hermoso, V., Morán-Ordóñez, A., Lanzas, M., Brotons, L., 2020. Designing a network of green infrastructure for the EU. Landscape and Urban Planning 196, 103732. https://doi.org/10.1016/j.landurbplan.2019.103732

IUCN. (2020a). Global Standard for Nature-based Solutions: A user-friendly framework for the verification, design and scaling up of NBS : first edition. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.08.en

IUCN. (2020b). Guidance for using the IUCN Global Standard for Nature-based Solutions: First editions (1.a ed.). IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.09.en

Joosten, H., Gaudig, G., Tanneberger, F., Wichmann, S., Wichtmann, W., 2016. Paludiculture: sustainable productive use of wet and rewetted peatlands, in: Bonn, A., Allott, T., Evans, M., Joosten, H., Stoneman, R. (Eds.), Peatland Restoration and Ecosystem Services. Cambridge University Press, pp. 339–357. https://doi.org/10.1017/CBO9781139177788.018

Kathage, J., Smit, B., Janssens, B., Haagsma, W., Adrados, J.L., 2022. How much is policy driving the adoption of cover crops? Evidence from four EU regions. Land Use Policy 116, 106016. https://doi.org/10.1016/j.landusepol.2022.106016

Kazmierczak, A., Carter, J., 2010. Adaptation to climate change using green and blue infrastructure: a database of case studies | PreventionWeb [WWW Document]. URL https://www.preventionweb.net/publication/adaptation-climate-change-using-green-and-blue-infrastructure-database-case-studies (accessed 10.31.23).

Kim, N., Zabaloy, M.C., Guan, K., Villamil, M.B., 2020. Do cover crops benefit soil microbiome? A meta-analysis of current research. Soil Biology and Biochemistry 142, 107701. https://doi.org/10.1016/j.soilbio.2019.107701

Knoke, T., Messerer, K., Paul, C., 2017. The Role of Economic Diversification in Forest Ecosystem Management. Curr Forestry Rep 3, 93–106. https://doi.org/10.1007/s40725-017-0054-3

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Knoke, T., Stimm, B., Ammer, C., Moog, M., 2005. Mixed forests reconsidered: A forest economics contribution on an ecological concept. Forest Ecology and Management 213, 102–116. https://doi.org/10.1016/j.foreco.2005.03.043

Koontz, M.J., North, M.P., Werner, C.M., Fick, S.E., Latimer, A.M., 2020. Local forest structure variability increases resilience to wildfire in dry western U.S. coniferous forests. Ecology Letters 23, 483–494. https://doi.org/10.1111/ele.13447

Lahtinen, L., Mattila, T., Myllyviita, T., Seppälä, J., Vasander, H., 2022. Effects of paludiculture products on reducing greenhouse gas emissions from agricultural peatlands. Ecological Engineering 175, 106502. https://doi.org/10.1016/j.ecoleng.2021.106502

Laishram, J., Saxena, K., Maikhuri, R., Rao, K., 2012. Soil quality and soil health: A review. International Journal of Ecology and Environmental Sciences.

Lal, R., 2015. Soil carbon sequestration and aggregation by cover cropping. Journal of Soil and Water Conservation 70, 329–339. https://doi.org/10.2489/jswc.70.6.329

Lamond, J., Everett, G., 2019. Sustainable Blue-Green Infrastructure: A social practice approach to understanding community preferences and stewardship. Landscape and Urban Planning 191, 103639. https://doi.org/10.1016/j.landurbplan.2019.103639

Langemeyer, J., Baró, F., 2021. Nature-based solutions as nodes of green-blue infrastructure networks: A cross-scale, co-creation approach. Nature-Based Solutions 1, 100006. https://doi.org/10.1016/j.nbsj.2021.100006

LaRose, J., Myers, R., n.d. Cover crops: a cost-effective tool for controlling erosion.

Larsen, J.B., Angelstam, P., Bauhus, J., Carvalho, J.F., Diaci, J., Dobrowolska, D., Gazda, A., Gustafsson, L., Krumm, F., Knoke, T., Konczal, A., Kuuluvainen, T., Mason, B., Motta, R., Pötzelsberger, E., Rigling, A., Schuck, A., 2022. Closer-to-Nature Forest Management (From Science to Policy), From Science to Policy. European Forest Institute. https://doi.org/10.36333/fs12

Li, J., Jiang, R., Tang, X., 2022. Assessing psychological factors on farmers' intention to apply organic manure: an application of extended theory of planned behavior. Environ Dev Sustain. https://doi.org/10.1007/s10668-022-02829-y

Liedekerke, M.V., Prokop, G., Rabl-Berger, S., Kibblewhite, M., Geertrui Louwagie, 2014. Progress in the Management of Contaminated Sites in Europe. https://doi.org/10.13140/RG.2.1.4213.5444

Luhas, J., Mikkilä, M., Uusitalo, V., Linnanen, L., 2019. Product Diversification in Sustainability Transition: The Forest-Based Bioeconomy in Finland. Sustainability 11, 3293. https://doi.org/10.3390/su11123293

Maltais-Landry, G., Nesic, Z., Grant, N., Godinez, M., Thompson, B., Hsu, L.-Y., Smukler, S.M., 2019. Quantifying trade-offs among on-farm and off-farm fertility sources to make vegetable organic farming systems more sustainable. Agriculture, Ecosystems & Environment 286, 106657. https://doi.org/10.1016/j.agee.2019.106657

Megharaj, M., Naidu, R., 2017. Soil and brownfield bioremediation. Microbial Biotechnology 10, 1244–1249. https://doi.org/10.1111/1751-7915.12840

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Messier, C., Bauhus, J., Sousa-Silva, R., Auge, H., Baeten, L., Barsoum, N., Bruelheide, H., Caldwell, B., Cavender-Bares, J., Dhiedt, E., Eisenhauer, N., Ganade, G., Gravel, D., Guillemot, J., Hall, J.S., Hector, A., Hérault, B., Jactel, H., Koricheva, J., Kreft, H., Mereu, S., Muys, B., Nock, C.A., Paquette, A., Parker, J.D., Perring, M.P., Ponette, Q., Potvin, C., Reich, P.B., Scherer-Lorenzen, M., Schnabel, F., Verheyen, K., Weih, M., Wollni, M., Zemp, D.C., 2022. For the sake of resilience and multifunctionality, let's diversify planted forests! CONSERVATION LETTERS 15, e12829. https://doi.org/10.1111/conl.12829

Mitchell, J.P., Shrestha, A., Irmak, S., 2015. Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California. Journal of Soil and Water Conservation 70, 430–440. https://doi.org/10.2489/jswc.70.6.430

Nemcová, T., Caiati, S., 2022. Peatlands and wetlands in the new CAP: too little action to protect and restore.

Nikolić, M., Stevović, S., 2015. Family Asteraceae as a sustainable planning tool in phytoremediation and its relevance in urban areas. Urban Forestry & Urban Greening 14, 782–789. https://doi.org/10.1016/j.ufug.2015.08.002

Nkamleu, G.B., Adesina, A.A., 2000. Determinants of chemical input use in peri-urban lowland systems: bivariate probit analysis in Cameroon. Agricultural Systems 63, 111–121. https://doi.org/10.1016/S0308-521X(99)00074-8

Oberč, B.P., Arroyo Schnell, A., 2020. Approaches to sustainable agriculture: exploring the pathways towards the future of farming. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.07.en

O'Connor, D., Zheng, X., Hou, D., Shen, Z., Li, G., Miao, G., O'Connell, S., Guo, M., 2019. Phytoremediation: Climate change resilience and sustainability assessment at a coastal brownfield redevelopment. Environment International 130, 104945. https://doi.org/10.1016/j.envint.2019.104945

Pakzad, P., Osmond, P., Corkery, L., 2017. Developing Key Sustainability Indicators for Assessing Green Infrastructure Performance. Procedia Engineering 180, 146–156. https://doi.org/10.1016/j.proeng.2017.04.174

Paletto, A., Hamunen, K., De Meo, I., 2015. Social Network Analysis to Support Stakeholder Analysis in Participatory Forest Planning. Society & Natural Resources 28, 1108–1125. https://doi.org/10.1080/08941920.2015.1014592

Palliwoda, J., Haase, A., Suppee, C., Rink, D., Priess, J.A., 2022. Visions for development and management of urban green and blue infrastructure: a citizen's perspective. E&S 27, art8. https://doi.org/10.5751/ES-13129-270208

Panagos, P., Van Liedekerke, M., Yigini, Y., Montanarella, L., 2013. Contaminated Sites in Europe: Review of the Current Situation Based on Data Collected through a European Network. Journal of Environmental and Public Health 2013, 1–11. https://doi.org/10.1155/2013/158764

Pandey, V.C., Souza-Alonso, P., 2019. Market Opportunities: in Sustainable Phytoremediation, in: Phytomanagement of Polluted Sites. Elsevier, pp. 51–82. https://doi.org/10.1016/B978-0-12-813912-7.00002-8

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.
UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Pelyukh, O., Lavnyy, V., Paletto, A., Troxler, D., 2021. Stakeholder analysis in sustainable forest management: An application in the Yavoriv region (Ukraine). Forest Policy and Economics 131, 102561. https://doi.org/10.1016/j.forpol.2021.102561

Pelyukh, O., Paletto, A., 2019. Stakeholder Analysis to Support Secondary Norway Spruce (Picea abies (L.) Karst.) Forest Conversion in the Ukrainian Carpathians. Acta Silvatica et Lignaria Hungarica 15, 69–84. https://doi.org/10.2478/aslh-2019-0006

Prasetyaningtyas, S.W., Sobir, S., Hermawan, A., Maarif, M.S., 2019. Utilizing Stakeholders Analysis on Sustainable Organic Farming in West Java: The Case of Cisarua Organic Farming. JMA. https://doi.org/10.17358/jma.16.1.56

Rambaut, L.-A.E., Tillard, E., Vayssières, J., Lecomte, P., Salgado, P., 2022. Trade-off between short and long-term effects of mineral, organic or mixed mineral-organic fertilisation on grass yield of tropical permanent grassland. European Journal of Agronomy 141, 126635. https://doi.org/10.1016/j.eja.2022.126635

Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation 141, 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014

Reed, M.S., Young, D.M., Taylor, N.G., Andersen, R., Bell, N.G.A., Cadillo-Quiroz, H., Grainger, M., Heinemeyer, A., Hergoualc'h, K., Gerrand, A.M., Kieft, J., Krisnawati, H., Lilleskov, E.A., Lopez-Gonzalez, G., Melling, L., Rudman, H., Sjogersten, S., Walker, J.S., Stewart, G., 2022. Peatland core domain sets: building consensus on what should be measured in research and monitoring. Mires Peat 28, 1–21. https://doi.org/10.19189/MaP.2021.OMB.StA.2340

Reganold, J.P., Wachter, J.M., 2016. Organic agriculture in the twenty-first century. Nature Plants 2, 15221. https://doi.org/10.1038/nplants.2015.221

Rehschuh, S., Jonard, M., Wiesmeier, M., Rennenberg, H., Dannenmann, M., 2021. Impact of European Beech Forest Diversification on Soil Organic Carbon and Total Nitrogen Stocks–A Meta-Analysis. Front. For. Glob. Change 4, 606669. https://doi.org/10.3389/ffgc.2021.606669

Roesch-McNally, G.E., Basche, A.D., Arbuckle, J.G., Tyndall, J.C., Miguez, F.E., Bowman, T., Clay, R., 2018. The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. Renew. Agric. Food Syst. 33, 322–333. https://doi.org/10.1017/S1742170517000096

Roessiger, J., Griess, V.C., Knoke, T., 2011. May risk aversion lead to near-natural forestry? A simulation study. Forestry: An International Journal of Forest Research 84, 527–537. https://doi.org/10.1093/forestry/cpr017

Roley, S.S., Tank, J.L., Tyndall, J.C., Witter, J.D., 2016. How cost-effective are cover crops, wetlands, and two-stage ditches for nitrogen removal in the Mississippi River Basin? Water Resources and Economics 15, 43–56. https://doi.org/10.1016/j.wre.2016.06.003

Rowan, N.J., Murray, N., Qiao, Y., O'Neill, E., Clifford, E., Barceló, D., Power, D.M., 2022. Digital transformation of peatland eco-innovations ('Paludiculture'): Enabling a paradigm shift towards the real-time sustainable production of 'green-friendly' products and services. Science of The Total Environment 838, 156328. https://doi.org/10.1016/j.scitotenv.2022.156328

Co-funded by the European Union
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation
This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Schäfer, A., 2012. Paludiculture for biodiversity and climate – economics of rewetted peatlands. Presented at the Proceedings of the European Conference on Biodiversity and Climate Change 2011, Bonn, Germany, pp. 63–64.

Schwitzguébel, J.-P., van der Lelie, D., Baker, A., Glass, D.J., Vangronsveld, J., 2002. Phytoremediation: European and American trends successes, obstacles and needs. J Soils & Sediments 2, 91–99. https://doi.org/10.1007/BF02987877

Scott, A., Bader, E., Dempsey, N., 2023. Case studies of blue-green infrastructure in spatial planning, in: ICE Manual of Blue-Green Infrastructure, ICE Manuals. ICE Publishing, pp. 287–303. https://doi.org/10.1680/icembgi.65420.287

Seufert, V., Ramankutty, N., 2017. Many shades of gray—The context-dependent performance of organic agriculture. Sci. Adv. 3, e1602638. https://doi.org/10.1126/sciadv.1602638

Shackelford, G.E., Kelsey, R., Dicks, L.V., 2019. Effects of cover crops on multiple ecosystem services: Ten meta-analyses of data from arable farmland in California and the Mediterranean. Land Use Policy 88, 104204. https://doi.org/10.1016/j.landusepol.2019.104204

Sharma, B., Vaish, B., Monika, Singh, U.K., Singh, P., Singh, R.P., 2019. Recycling of Organic Wastes in Agriculture: An Environmental Perspective. Int J Environ Res 13, 409–429. https://doi.org/10.1007/s41742-019-00175-y

Shea, E.C., 2014. Adaptive management: The cornerstone of climate-smart agriculture. Journal of Soil and Water Conservation 69, 198A-199A. https://doi.org/10.2489/jswc.69.6.198A

Smit, B., Janssens, B., Haagsma, W., Hennen, W., Adrados, J.L., Kathage, J., Pérez Domínguez, I., 2019. Adoption of cover crops for climate change mitigation in the EU. Publications Office of the European Union, Luxembourg,. https://doi.org/doi:10.2760/638382,

Song, Y., Hou, D., Zhang, J., O'Connor, D., Li, G., Gu, Q., Li, S., Liu, P., 2018. Environmental and socio-economic sustainability appraisal of contaminated land remediation strategies: A case study at a mega-site in China. Science of The Total Environment 610–611, 391–401. https://doi.org/10.1016/j.scitotenv.2017.08.016

Sörensen, J., Persson, A.S., Olsson, J.A., 2021. A data management framework for strategic urban planning using blue-green infrastructure. Journal of Environmental Management 299, 113658. https://doi.org/10.1016/j.jenvman.2021.113658

Stigter, T.Y., 2011. Restoration of Groundwater Quality to Sustain Coastal Ecosystems Productivity, in: Treatise on Estuarine and Coastal Science. Elsevier, pp. 245–262. https://doi.org/10.1016/B978-0-12-374711-2.01013-5

Sumberg, J., Giller, K.E., 2022. What is 'conventional' agriculture? Global Food Security 32, 100617. https://doi.org/10.1016/j.gfs.2022.100617

Swanson, K., Schnitkey, G., Armstrong, S., Coppess, J., 2018. Understanding Budget Implications of Cover Crops. farmdoc daily, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, 8.

Tanneberger, F., Birr, F., Couwenberg, J., Kaiser, M., Luthardt, V., Nerger, M., Pfister, S., Oppermann, R., Zeitz, J., Beyer, C., van der Linden, S., Wichtmann, W., Närmann, F., 2022. Saving soil carbon, greenhouse

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

gas emissions, biodiversity and the economy: paludiculture as sustainable land use option in German fen peatlands. Reg Environ Change 22, 69. https://doi.org/10.1007/s10113-022-01900-8

Tanneberger, F., Martens, H., Laage, K., Eickmanns, M., Heinsohn, V., Wegner, N., Muster, C., Diekmann, M., Kreyling, J., Michalik, P., Seeber, E., Drexler, A., 2023. Paludiculture can support biodiversity conservation in rewetted fen peatlands (preprint). In Review. https://doi.org/10.21203/rs.3.rs-2800490/v1

Taramelli, Lissoni, Piedelobo, Schiavon, Valentini, Xuan, González-Aguilera, 2019. Monitoring Green Infrastructure for Natural Water Retention Using Copernicus Global Land Products. Remote Sensing 11, 1583. https://doi.org/10.3390/rs11131583

Tata, H.L., 2019. Paludiculture: can it be a trade-off between ecology and economic benefit on peatland restoration? IOP Conf. Ser.: Earth Environ. Sci. 394, 012061. https://doi.org/10.1088/1755-1315/394/1/012061

Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L.A., Bengtsson, J., 2014. Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. J Appl Ecol 51, 746–755. https://doi.org/10.1111/1365-2664.12219

Turkelboom, F., Leone, M., Jacobs, S., Kelemen, E., García-Llorente, M., Baró, F., Termansen, M., Barton, D.N., Berry, P., Stange, E., Thoonen, M., Kalóczkai, Á., Vadineanu, A., Castro, A.J., Czúcz, B., Röckmann, C., Wurbs, D., Odee, D., Preda, E., Gómez-Baggethun, E., Rusch, G.M., Pastur, G.M., Palomo, I., Dick, J., Casaer, J., Van Dijk, J., Priess, J.A., Langemeyer, J., Mustajoki, J., Kopperoinen, L., Baptist, M.J., Peri, P.L., Mukhopadhyay, R., Aszalós, R., Roy, S.B., Luque, S., Rusch, V., 2018. When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. Ecosystem Services 29, 566–578. https://doi.org/10.1016/j.ecoser.2017.10.011

Valente De Macedo, L.S., Barda Picavet, M.E., Puppim De Oliveira, J.A., Shih, W.-Y., 2021. Urban green and blue infrastructure: A critical analysis of research on developing countries. Journal of Cleaner Production 313, 127898. https://doi.org/10.1016/j.jclepro.2021.127898

Vaneeckhaute, C., Meers, E., Michels, E., Buysse, J., Tack, F.M.G., 2013. Ecological and economic benefits of the application of bio-based mineral fertilizers in modern agriculture. Biomass and Bioenergy 49, 239–248. https://doi.org/10.1016/j.biombioe.2012.12.036

Verdone, M., 2015. A Cost-Benefit Framework for Analyzing Forest Landscape Restoration Decisions.

Vukicevich, E., Lowery, T., Bowen, P., Úrbez-Torres, J.R., Hart, M., 2016. Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture. A review. Agron. Sustain. Dev. 36, 48. https://doi.org/10.1007/s13593-016-0385-7

Wan, X., Lei, M., Chen, T., 2016. Cost–benefit calculation of phytoremediation technology for heavy-metal-contaminated soil. Science of The Total Environment 563–564, 796–802. https://doi.org/10.1016/j.scitotenv.2015.12.080

Wang, L., Rinklebe, J., Tack, F.M.G., Hou, D., 2021. A review of green remediation strategies for heavy metal contaminated soil. Soil Use and Management 37, 936–963. https://doi.org/10.1111/sum.12717

Wang, X., Ma, Y., Li, H., Xue, C., 2022. How Does Risk Management Improve Farmers' Green Production Level? Organic Fertilizer as an Example. Front. Environ. Sci. 10, 946855. https://doi.org/10.3389/fenvs.2022.946855

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Ward, O.P., 2004. The industrial sustainability of bioremediation processes. Journal of Industrial Microbiology and Biotechnology 31, 1–4. https://doi.org/10.1007/s10295-004-0109-x

West, T.A.P., Salekin, S., Melia, N., Wakelin, S.J., Yao, R.T., Meason, D., 2021. Diversification of forestry portfolios for climate change and market risk mitigation. Journal of Environmental Management 289, 112482. https://doi.org/10.1016/j.jenvman.2021.112482

Westerman, P.W., Bicudo, J.R., 2005. Management considerations for organic waste use in agriculture. Bioresource Technology 96, 215–221. https://doi.org/10.1016/j.biortech.2004.05.011

Wichmann, S., 2017. Commercial viability of paludiculture: A comparison of harvesting reeds for biogas production, direct combustion, and thatching. Ecological Engineering, Wetlands and buffer zones in watershed management 103, 497–505. https://doi.org/10.1016/j.ecoleng.2016.03.018

Wichtmann, W., Joosten, H., 2007. Paludiculture: Peat formation and renewable resources from rewetted peatlands. IMCG Newsletter 3.

Wichtmann, W., Tanneberger, F., Wichmann, S., Joosten, H., 2010. Paludiculture is paludifuture. Climate, biodiversity and economic benefits from agriculture and forestry on rewetted peatland. Peatlands International 48–51.

Wilker, J., Rusche, K., Rymsa-Fitschen, C., 2016. Improving Participation in Green Infrastructure Planning. Planning Practice & Research 31, 229–249. https://doi.org/10.1080/02697459.2016.1158065

Wuijts, S., Fraters, D., Boekhold, S., Van Duijnen, R., 2022. Monitoring of nitrogen in water in the EU: legal framework, effects of nitrate, design principles, effectiveness and future developments. European Parliament, Brussels.

Xie, J., Yang, G., Guo, Z., Wang, G., 2021. Exploring the Influence Mechanism of Farmers' Organic Fertilizer Application Behaviors Based on the Normative Activation Theory. Land 10, 1111. https://doi.org/10.3390/land10111111

Xu, H., Huang, X., Zhong, T., Chen, Z., Yu, J., 2014. Chinese land policies and farmers' adoption of organic fertilizer for saline soils. Land Use Policy 38, 541–549. https://doi.org/10.1016/j.landusepol.2013.12.018

Xu, W., Zhou, C., Cao, A., Luo, M., 2016. Understanding the mechanism of food waste management by using stakeholder analysis and social network model: An industrial ecology perspective. Ecological Modelling 337, 63–72. https://doi.org/10.1016/j.ecolmodel.2016.06.006

Yoder, L., Houser, M., Bruce, A., Sullivan, A., Farmer, J., 2021. Are climate risks encouraging cover crop adoption among farmers in the southern Wabash River Basin? Land Use Policy 102, 105268. https://doi.org/10.1016/j.landusepol.2020.105268

Ziegler, R., 2020. Paludiculture as a critical sustainability innovation mission. Research Policy 49, 103979. https://doi.org/10.1016/j.respol.2020.103979

Ziegler, R., Wichtmann, W., Abel, S., Kemp, R., Simard, M., Joosten, H., 2021. Wet peatland utilisation for climate protection – An international survey of paludiculture innovation. Cleaner Engineering and Technology 5, 100305. https://doi.org/10.1016/j.clet.2021.100305

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Co-funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

UK Research
and Innovation

This work has received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10061997.

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).