DISCUSSION PAPER: NATURE-BASED SOLUTIONS IN FOOD SYSTEMS

Review of nature-based solutions towards more sustainable agriculture and food production

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Abstract

This discussion paper aims to provide information to the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) on NbS to understand more about the principles upon which NbS are based for sustainable agriculture and food systems. This research also aims to contribute to an operational framework that could guide applications of NbS on different regions in the world and at different scales, as well to provide relevant scientific material for the development of future policy guidelines.

Desktop research was conducted through literature review and using secondary data. NbS case studies for food production implemented in the Netherlands, in Europe, and in the global south (Latin America, Africa, and Asia) were collected and reviewed.

This discussion paper is organized in the following way: Firstly, definitions, principles and concepts of NbS are explained in section 2. Moreover, section 3 is about the application of NbS for food security and circularity under climate change conditions. Case studies from the Netherlands, Europe and the global south are mentioned. Section 4 explains the drivers, opportunities, and hindering factors for the successful implementation of NbS in different socio-ecological and climatic contexts. NbS across different scales are described in section 5 with reference to different case studies. Section 6 relates to the factors that support multi-stakeholders' participation, the available NbS tools and data, along with the description of business models to jointly explore the potential for NbS applications. We then turn to present our conclusions and recommendations addressed in section 7.

Keywords: Nature-Based Solutions, Food System, Sustainable Food Production, Climate Resilience.

Executive Summary

Nature-based Solutions (NbS) seek to enhance the capacity and ability of nature to provide ecosystem services as long-term approaches to tackle environmental and societal challenges.

The main objective of this discussion paper is to provide information to the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) on NbS to understand more about the principles upon which NbS are based for sustainable agriculture and food systems. This research also aims to contribute to an operational framework that could guide applications of NbS on different regions in the world and at different scales, as well to support LNV with relevant material on the subject for the development of future policy guidelines.

To address NbS from a food system perspective, the research focused on food production in rural areas. As climate change involves adaptation and mitigation measures, we limited the research to climate adaptation.

Desktop research was conducted to gather secondary data on the subject. NbS case studies implemented in the Netherlands, in Europe, and in the global south (Latin America, Africa, and Asia) were reviewed.

This discussion paper provides information and knowledge relevant for decision makers to assist on the development of policy towards NbS uptake. This study improves our theoretical understanding of NbS towards sustainable agriculture and food production.

The research questions that guided this discussion paper and key findings are:

1. **Which are the NbS definitions, principles and concepts mostly used for sustainable agriculture and food systems?**
    - There are different definitions that various international organizations use. The definition of NbS from the European Commission (EC) can be used under European and Dutch contexts, whereas the IUCN's and UNEA's definitions can be applied indistinctively for the global north and for the global south contexts.
    - NbS principles should embrace nature protection, rehabilitation and management but not all the interventions could be considered NbS, because not every NbS can be implemented everywhere.
    - We identified three types of NbS: Intrinsic (to make better use of existing natural or protected ecosystems), Hybrid (based on modifying managed or restored ecosystems) and Inspired (involve the creation of new ecosystems and/or the use of new technologies copying ecosystems to increase service provision sustainably).
    - Concepts such as Climate-smart agriculture (CSA), Agroecology, and Nature-Based Solutions (NbS) have different origins, and different scientific and political progressions.
    - NbS seems to be an umbrella concept overarching other terminologies and interventions towards sustainable and resilient agricultural production, such as blue-green infrastructure, agroforestry, regenerative agriculture, nature-inclusive agriculture, permaculture, to mention a few.

2. **How do NbS contribute to food security and circularity under climate change conditions?**
    - NbS could be seen as cost-effective interventions to adapt agriculture in a changing climate, as well as measures to enhance resilience and food security.
    - NbS for food production can be adopted with single interventions and in conjunction with other types of measures to achieve food security, environmental protection, restore biodiversity, address societal challenges and climate change targets.
    - Circular food systems aim to optimize the use of resources. NbS for food production could encourage the use of regenerative resources and add value to the food system.
3. **Which are the drivers, opportunities and hindering factors for successful implementation of NbS in the food system?**
    - Some NBS drivers identified were climate risks, a shift in the societal valuation of ecologically sound practices, and a pragmatic approach to problem-solving where NbS can be cost-effective.
    - Opportunities and potential for an accelerated uptake are shown when powerful market players and stakeholders adopt NbS and introduce them to the regime.
    - Hindering factors originate from knowledge gaps, institutional lack of vision, resistance from dominant regimes or even stakeholders to adopt NbS and financial limitations.
    - Without proper attention to an inclusive approach, inequality and injustice will pose a risk towards NbS uptake.
4. **What kind of NbS case studies at different scales and geographical regions can be found as examples for NbS implementation in the food system?**
    - The different NbS case studies in the Netherlands, Europe and global south, mentioned directly or indirectly their contributions to the environment (e.g. water management to improve water quantity and quality), climate change (e.g. carbon sequestration or climate adaptation for disaster risk reduction), biodiversity (e.g. improving habitats and support of local species), and socio-economic and cultural contributions (e.g. human health and wellbeing or improving agricultural output and income).
    - Temporal scales for NbS implementation have an important impact on calculating the cost-benefit of different measures and even support the planning of NbS business models.
    - Geographic, spatial and temporal scales are relevant to identifying the types of policies, legal, governance and financial mechanisms that can support NbS implementation for sustainable food production.
    - The effectiveness of NbS is related to the scale of implementation (e.g., country, regional, landscape, farm level) and foremost to the acceptance and ownership of multiple stakeholders.

5. **What are the factors supporting multi-stakeholders participation, the available NbS tools and NbS business models that could jointly explore potentials for NbS?**
   - For the NbS projects it is important to consider the complex biophysical and political context, the culture and socio-economic factors of the agricultural producers and organizations involved, which vary widely by individuals, gender, type of landowners, and business size.
   - Climate adaptation and mitigation challenges are also to be considered, along with the specific constraints that different stakeholders face, including access to natural resources, credit, markets, and infrastructure.
   - There is not just one intended user (group) nor one specific part of the NbS uptake process that should be supported by NbS tools. There are different potential end-users such as food organizations, farmers and other agricultural producers, government officers, scientists, practitioners, and community organizations, among others that can make use of NbS tools.
   - An NbS Business Model Canvas can help to identify significant economic and societal benefits for agri-food actors, businesses and governments. Investments in NbS projects are increasing as they create a positive return for society and the environment.

It is concluded that even though NbS is a rather new (umbrella) concept, and several definitions exist, every definition aims at using natural processes to address societal and environmental challenges. However, the preference for one definition over another is often related to the purpose and context of the user.

Nature and ecosystem dynamics are an inspiration to move from linear to circular food production systems when possible. Nevertheless, we need to be aware that the viable implementation of nature-based and circular solutions in our society and current economic system requires interdisciplinary integrated solutions towards food security, financial and legal modifications, and climate change considerations.

The NbS case studies illustrate a certain scale and purpose for agriculture and food production in the Netherlands, Europe and the global south. The NbS examples showed that every solution implies pros and cons. Therefore, feasibility studies are recommended for NbS projects along with the identification of drivers, barriers and opportunities.

Different stakeholders have different views on problems and on solutions. Applying participatory approaches can help to increase acceptance. Likewise, making use of NbS tools and developing NbS business models, can support on the development of sustainable NbS projects for agriculture and food systems.

1.Introduction

Sustainably enhancing agricultural production and incomes, adapting and building the resilience of people and agri-food systems to climate change, and lowering and/or removing greenhouse gas emissions where applicable are the three guiding concepts of Nature-based Solutions (NbS) in farm systems (FAO, 2021a). The concept came about as a result of the search for novel ways to manage natural systems to balance the advantages for both nature and society. In other words, human societies may create and put into practice solutions for a resilient, resource-efficient, and green economy by working with nature rather than against it (Policy, 2021).

There is a growing interest in nature as a means and inspiration for solutions and design for climate adaptation, mitigation, and sustainable development. At key international agreements and events, like the Paris Agreement (2015), Sustainable Development Goals, Convention on Biological Diversity (CBD) 2021 UN Food Systems Summit, and the most recent agreements at the 26th UN Climate Change Conference of the Parties (COP26) 2021 in Glasgow, nature has been an essential topic of discussion for better integration of nature-based solutions into adaptation planning. Furthermore, to contribute to the objectives of the CBD, the post-2020 Global Biodiversity Framework (GBF) builds on an ambitious plan to implement broad-based action to bring about a transformation in society's relationship with biodiversity and to ensure that, by 2050, the shared vision of living in harmony with nature is fulfilled (The post-2020 GBF, 2022).

Notably, the European Union committed resolutions on Nature-based Solutions (NbS) to the GBF by proposing, *"whereas, according to the Intergovernmental Panel for Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), no lasting solutions exist to address climate change without a greater implementation of consistent and effective nature-based solutions"* (European, 2021). In addition, various local, regional, national, and international organizations have underlined the importance of nature, NbS, and the different range of ecosystems to address climate resilience, reduce total greenhouse gas emissions, contribute to people's wellbeing, and support biodiversity.

Worldwide organizations such as the United Nations Environment Assembly (UNEA) and the International Union for Conservation of Nature (IUCN) have published definitions and characteristics of NbS. For instance, the International Union for Conservation of Nature (IUCN) promoted NbS in 2009 on the United Nations Framework Convention on Climate Change – UNFCCC, COP15. The European Commission introduced NbS as part of its Horizon 2020 Research and Innovation Programme. The World Bank introduced the concept in 2008 and established 2017 the World Bank NbS Program. The World Wildlife Fund is promoting NbS globally and prioritizing climate actions. However, NbS is a relative new concept and not universally used in scientific research, management and policy. NbS includes a broader range of measures and interventions with safeguards that contribute to climate adaptation and mitigation.

There are many examples of how NbS can help to solve different societal challenges. However, there is fragmented knowledge and not a clear understanding on how they could be best utilized in the context of sustainable agriculture and food systems. The need for food systems to move towards a more sustainable provider of sufficient nutritious food for all people is evident. So far, the food system has a mixed track record in providing food and nutrition security and a poor track record when looking at the impacts on the environment, biodiversity, climate change, and social inclusiveness. The health and continuity of natural ecosystems are essential for human, economic, and social development. Therefore, NbS seek to enhance the capacity and ability of nature to provide ecosystem services as long-term approaches to tackle environmental and societal challenges.

The main objective of this discussion paper is to provide information to the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) on NbS to understand more about the principles upon which NbS are based for sustainable agriculture and food systems. This research also aims to contribute to an operational framework that could guide applications of NbS on different regions in the world and at different scales, as well to support LNV with relevant material on the subject for the development of future policy guidelines.

The research questions that guided this research are:

1. **Which are the NbS definitions, principles and concepts mostly used for sustainable agriculture and food systems?** There is a need to comprehend the similarities and differences between the several NbS definitions. Likewise, it is important to understand the main principles that NbS are based on and identify the different concepts and terms related to NbS in food systems.
2. **How do NbS contribute to food security and circularity under climate change conditions?** Climate change is a pressing concern that jeopardizes food security and natural resources, which simultaneously, enhances other environmental and socio-economic challenges. It is significant to investigate how NbS is starting to gain weight in the climate change discourse for food security and circularity.
3. **Which are the drivers, opportunities and hindering factors for successful implementation of NbS in the food system?** It is necessary to explain which are the main drivers around NbS in the food system, as well as the opportunities to foster NbS implementation and the technical, institutional, financial and social barriers to overcome.
4. **What kind of NbS case studies at different scales and geographical regions can be found as examples for NbS implementation in the food system?** This research question will help to identify several case studies of NbS at different scales in the global south, Europe, and in the Netherlands. These best practices could provide insights into the possible contributions, pros and cons, suitable scales, and types of NbS.
5. **What are the factors supporting multi-stakeholders participation, the available NbS tools and NbS business models that could jointly explore potentials for NbS?** These multiple questions will help to describe the incentives and/or disincentives of different stakeholders towards the adoption of NbS in the food system. Similarly, to review the tools and resources that could support end users in the planning, design, and implementation of NbS. Finally, to explain the NbS business models

that could enable businesses, farmers, food producers, governments and other actors to finance and invest on NbS projects.

To address NbS from a food system perspective, the research focused on food production since most of the information in this area was easier to find and NbS are mainly implemented for primary production. The scope of this research is rural and the urban areas, markets, value chain, and consumers are not included on this research. Additionally, food production is addressed by using an ecosystem- and landscape-based approach, where NbS is frequently utilized in conjunction with different forms of interventions. As climate change involves adaptation and mitigation measures, we limited the research to climate adaptation due to time constraints.

Desktop research was conducted through literature review and using secondary data (e.g., review of scientific articles, reports, and other online sources). We addressed some NbS case studies implemented in the Netherlands, in Europe, and in the global south (Latin America, Africa, and Asia). The main entry point were the NbS interventions applied at different scales to learn from such best practices.

This discussion paper provides information and knowledge relevant for enlightened decision making and to assist on the development of policy towards NbS implementation in the Netherlands and in the global south. This study will improve our theoretical understanding of NbS towards sustainable agriculture and food production.

2. Nature-based solutions and multiple definitions and related concepts

Nature-Based Solutions (NbS) is an umbrella concept involving a wide range of ecosystem-based approaches and their services to address societal challenges like climate change, food security, natural disasters, biodiversity loss and environmental degradation. NbS is a relatively new concept and is still in the process of being framed by many organizations, as mentioned in chapter 1. Therefore, there is a need to understand better the similarities and differences between the several NbS definitions and their guiding principles (Cohen-Shacham et al., 2019; EEA, 2021; World Wide Fund, 2021; WWF, 2022). There is no legal or universally agreed definition for NbS. However, the definitions for NbS from IUCN and UNEA are multilaterally agreed upon, showing an attempt toward a standard definition. As mentioned above, it is common for diverse groups or organizations to use different definitions if they can encompass working with nature and ecosystems rather than relying on conventional engineering solutions. In practice, indigenous people have been practicing NbS for centuries. This new NbS concept is mainly used for policy-making and scientific research.

The most popular NbS definitions have been developed and applied by the following organizations:

World Bank (WB)

The World Bank (WB) first used the term in 2008. In their report "Biodiversity, Climate Change, and Adaptation: Nature-Based Solutions," the WB did not develop a comprehensive definition of NbS; instead, it developed a collection of the World Bank's biodiversity portfolio to tackle adaptation to climate change (MacKinnon et al., 2008). In 2021, the WB released another report titled "A Catalogue of Nature-Based Solutions for Urban Resilience," where they defined NBS within an urban scope (World Bank, 2021):

"Nature-based solutions are approaches that use nature and natural processes for delivering infrastructure, services, and integrative solutions to meet the rising challenge of urban resilience. These interventions usually go beyond sectoral boundaries and require cross-sectoral partnership. NbS can provide multiple benefits to cities and address different societal challenges, including reducing disaster risk and building climate resilience while also contributing to restoring biodiversity, creating opportunities for recreation, improving human health, water, and food security, and supporting community wellbeing and livelihoods."

Based on this WB report, this definition is unsuitable for applying NbS in rural areas or at a landscape level encompassing food production and security**.**

International Union for Conservation of Nature (IUCN)

In 2012, the International Union for Conservation of Nature (IUCN) adopted NbS into its program and developed the definition that is most widely used today (Cohen-Shacham et al., 2016):

"Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems in ways that address societal challenges effectively

and adaptively, to provide both human well-being and biodiversity benefits. They are underpinned by benefits that flow from healthy ecosystems and target major challenges like climate change, disaster risk reduction, food and water security, health and are critical to economic development."

This IUCN definition entails a broader application of NbS, including for food and water security.

European Commission (EC)
The European Commission (EC) used the following NbS definition in the frame of Horizon Europe Calls (European Commission, 2016):

"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions."

This EC definition uses the terms landscapes and seascapes where rural areas and maritime ecosystems for food production could be implicit.

World Wildlife Fund (WWF)
The World Wildlife Fund (WWF) presented a report in 2021 titled "Powering nature: Creating the conditions to enable nature-based solutions." They embrace the definition of NbS developed by the IUCN (Pérez-Cirera et al., 2021). They emphasize three amendments regarding conceptualization, implementation, and scaling. They put forward that NbS can address the grand societal challenges of human health, disaster risk reduction, safeguarding access to clean water, ensuring food security, and mitigating and adapting to climate change. However, more recently, they have developed their definition of NbS for climate (World Wide Fund, 2021):

"Ecosystem conservation, management and/or restoration interventions intentionally planned to deliver measurable positive climate adaptation and /or mitigation benefits that have human development and biodiversity co-benefits managing anticipated climate risks to nature that can undermine their long-term effectiveness."

This definition addresses the dual climate and biodiversity crisis that the world is facing and where NbS can play a key role in addressing these two crises.

United Nations Environment Assembly (UNEA)
The Fifth Session of the United Nations Environment Assembly (UNEA-5) has made a resolution in March 2022, on adopting a multilaterally agreed definition of nature-based solutions (NbS), recognizing the important role they play in the global response to climate change and its social, economic and environmental effects (NBS Initiative, 2022):

"Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits."

This definition is in line with the UNEA's 14 resolutions to curb pollution, protect and restore nature worldwide, safeguard the rights of communities and indigenous peoples and to achieve the Sustainable Development Goals.

Overall understanding of the concepts of NbS from various organizations states that the “use of nature" should be regarded as a remedy rather than a hindrance to human endeavors because nature offers solutions to the world's problems.

2.1. Nature-based solutions: principles and types

An advantage of NbS as an approach to work with nature and to address environmental and societal challenges, is that diverse types of measures allow to think and work across disciplines. The breadth of what kind of NbS strategies and types of interventions are used for the food system are not as easily transmitted by the NbS definition alone. Therefore, they are further described in section 2.2 below.

The main idea behind NbS principles is that NbS should embrace nature conservation and that not all conservation efforts could be considered NbS (Cohen-Shacham et al., 2016). NbS can also offer one group or numerous solutions to solve societal challenges. They can be complemented and implemented alongside other interventions. NbS should support cultural and social components and values, considering that NbS are context-specific (in time and space) (Cohen-Shacham et al., 2016).

The IUCN proposed eight NbS principles (Cohen-Shacham et al., 2016), which are essential in providing a better understanding of the NbS definition(s):

1. Embrace nature conservation norms (and principles).
2. It can be implemented alone or in an integrated manner with other solutions to societal challenges (e.g., technological and engineering solutions).
3. They are determined by site-specific natural and cultural contexts, including traditional, local, and scientific knowledge.
4. Produce societal benefits fairly and equitably, in a manner that promotes transparency and broad participation.
5. Maintain biological and cultural diversity and the ability of ecosystems to evolve over time.
6. Are applied at a landscape scale.
7. Recognize and address the trade-offs between the production of a few immediate economic benefits for development and future options to produce the full range of ecosystem services.
8. They are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

Seddon et al. (2021) developed similar guiding principles for developing successful NbS as the IUCN. The first one is that NbS are not a substitute for the rapid phase-out of fossil fuels (no greenwash). The second principle is that NbS involve a wide range of ecosystems on land and in the sea, not just forests. The third principle is that NbS are implemented with the full engagement and consent of indigenous people and local communities in a way that respects their cultural and ecological rights. The fourth principle is that NbS should be explicitly designed to provide measurable benefits for biodiversity. For more explanation of the context of each principle, see Annex1, SI Table 1. The 2021 United Nations Climate Change Conference (COP26) exposed these four guiding principles.

Groot et al. (Groot et al., 2020) developed a typology of NbS (Figure 1), which is in line with the definition of the EC (European Commission) described earlier in this section. They identified three types of NbS, namely the intrinsic NbS, which use an existing ecosystem, and inspired NbS that mimic natural processes, and lastly, there is an intermediate one that is a hybrid of the two previous types:

- **Type 1-Intrinsic NbS:** make better use of existing natural or protected ecosystems. There is no or minimal intervention in the ecosystems involved. Intrinsic NbS maintain or boost the effects of certain ecosystem services in existing natural or weakly managed ecosystems. This type of NbS promotes better use of natural/protected ecosystems for the delivery of multiple ecosystem services (e.g., measures to increase fish stocks in an intact wetland to enhance food security). Intrinsic NbS have a direct positive impact on biodiversity at local but often at a wider scale.
- **Type 2- Hybrid NBS:** are based on modifying managed or restored ecosystems (e.g., re-establishing traditional agro-forestry systems based on commercial tree species to support poverty alleviation). Their impact on biodiversity may be direct or indirect on a local or large scale.
- **Type 3- Inspired NBS:** involve the creation of new ecosystems and/or using innovative technologies copying ecosystems to increase service provision sustainably. Their impact on biodiversity is often indirect and at the local scale. Examples include the controlled use of modified micro-organisms in fermentation processes to synthesize food ingredients as flavours or exploiting the genetic diversity of plants in natural pest control or the use of helophyte filters for treating wastewater. Their impact on biodiversity may be direct or indirect on a local or large scale.

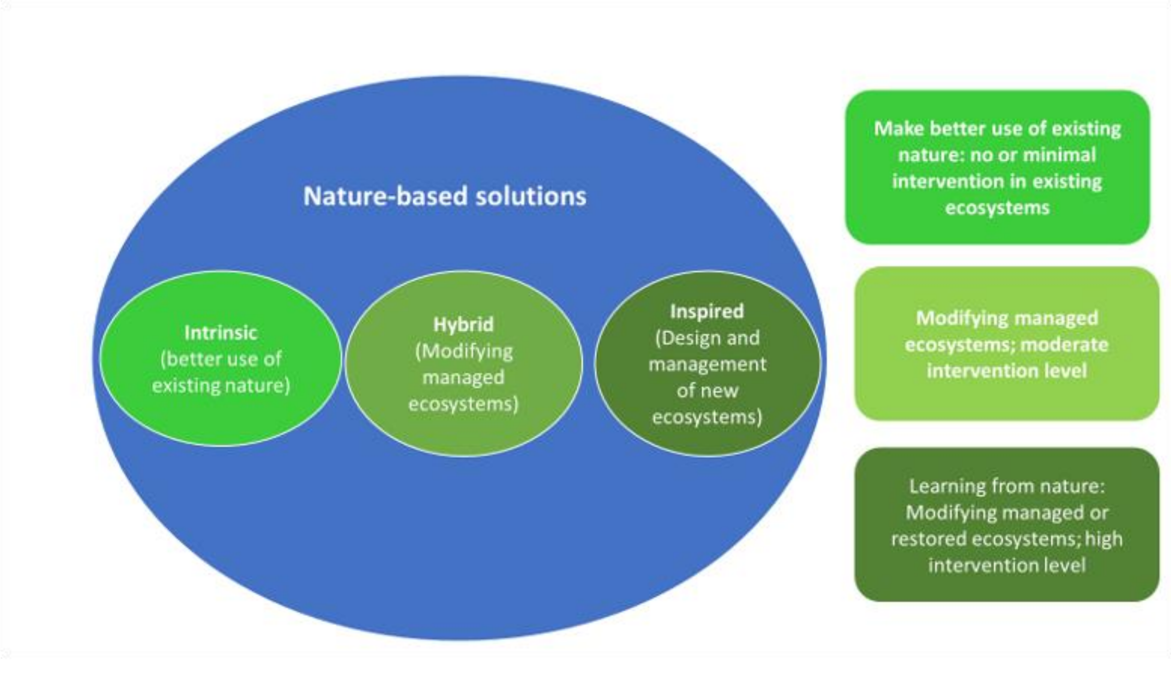

FIGURE 1. TYPOLOGY OF NATURE-BASED SOLUTIONS: INTRINSIC, INSPIRED, AND HYBRID SOLUTIONS (SOURCE: GROOT ET AL., 2020).

An advantage of NbS as an approach to work with nature and address environmental and societal challenges is that it allows communication and work across disciplines as being in use in different domains. This explains why the breadth of what kind of NbS strategies and interventions are used for the agri-food sector is not as quickly transmitted by the NbS definition alone. Therefore, they are further described in section 2.2 below.

2.2. Concepts and terms related to nature-based solutions in food systems

Food systems cover all aspects of food production and consumption. So, all the inputs, transport, processing and manufacturing industry, retail, and consumption, are considered, but their impacts on the environment, health, and society are also considered (Joachim von Braun et al., 2020). A sustainable food system is defined by the FAO (Food and Agriculture Organization) (*Food Systems*, 2022) as *"A system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generation is not compromised."* The scope of this research is on food production only, and we discuss the possibilities of NbS to contribute to making food systems more sustainable.

A Scopus search carried out by the authors on 10 December 2021 revealed 1,392 hits on "nature-based solution," plus "food system," which narrowed down to 79 hits, while "NbS and agriculture" yielded 109 hits. This was not yet many. It is a quickly developing field: the numbers seven months later (6 July 2022) are 1878, 118, and 645, respectively. What is striking here is that the subject areas indicated by Scopus for these searches are primarily environmental, followed by both, more or less at par, social sciences and agricultural & biological sciences. The tendency of NbS to get the most attention in the environmental sciences hints at its preferred user group or respective school of thinking. It is also not surprising that environmental scientists focus on nature first, while agricultural scientists may have other preferences or concerns in their approaches and would generally phrase the terms differently (such as agroecology, for instance, where agricultural & biological sciences are mentioned first).

An interesting scientific paper by Hrabanski & Le Cog (Hrabanski and Le Coq, 2022) traced concepts such as Climate-smart agriculture (CSA), Agroecology, and Nature-Based Solutions (NbS) and differentiated their origins, scientific and political progressions for agricultural adaptation and mitigation issues in the context of climate change. Table 1 below shows a summary of the conceptual definitions. The detailed table developed by the authors can be found in Annex 2, SI Table 2.

TABLE 1. SUMMARY OF THE CONCEPTS OF AGROECOLOGY, CLIMATE-SMART AGRICULTURE (CSA), AND NATURE-BASED SOLUTIONS (NBS). (ADAPTED FROM HRABANSKI AND LE COQ, 2022).

	Agroecology	CSA	NbS
Definition	The agroecological approach regards farm systems as the fundamental units of study, and mineral cycles, energy transformations, biological processes, and socioeconomic relationships in these systems are analyzed as a whole (Altieri et al., 2015).	This is agriculture that sustainably increases productivity and resilience (adaptation), reduces GHG (mitigation), and achieves national food security and development goals (F. Miralles-Wilhelm and T. Iseman, 2021)	These are actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2016).

According to Hrabanski & Le Cog, since the late 2000s, academic and/or civil society supporters of agroecology have stressed that climate change adaptation and mitigation objectives are pivotal to agroecology. Their positioning has been more reactive, as they were initially concerned about proposing an alternative model to the conventional green revolution paradigm and criticism of agricultural modernization. The CSA epistemic community, led by FAO and CGIAR, also worked toward the reconciliation of agriculture and the climate agenda but more proactively by creating the CSA concept intentionally to support agricultural integration into food security and climate arenas. NbS' new concept addresses societal challenges, along with climate change mitigation and adaptation issues that can simultaneously provide human wellbeing and biodiversity benefits (Hrabanski and Le Coq, 2022; Seddon et al., 2021).

Seddon et al. (2021) and Simelton et al. (Simelton et al., 2021) have also gathered different terms that enable the design and implementation of NbS to tackle different societal challenges. These terms fall under the umbrella of NbS, as they all focus on natural processes. Table 2 below summarizes the main terms that could be applied to food systems (food production). This table is not an exhaustive list.

Table 2. Summary of terms that fall under the umbrella of NbS that could be applied to food systems (Adapted from Seddon et al., 2021; Simelton et al., 2021; Westerink et al., 2021).

Term	Definition	References
Ecological engineering	The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both.	(Mitsch and Jørgensen, 2003; Odum, 1962)
Ecosystem-based adaptation (EbA)	The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change.	(Biodiversity and Mitigation, 2009)
Green/blue infrastructure (GI/GBI/BI)	A strategically planned and managed, spatially interconnected network of multi-functional natural, semi-natural, and man-made green and blue features, including agricultural land, green corridors, urban parks, forest reserves, wetlands, rivers, coastal and other aquatic ecosystems.	(European Commission, 2013)
	Primarily for engineering purposes, including physical regulation of water and soil, and slope stabilization, e.g., grass strips, hedgerows, or terraces using natural material. Benefits include reduced damage by mass movement or additional fodder grass.	Simelton, et al. (Simelton et al., 2021)
Integrated land management (ILM), Sustainable land management (SLM), Catchment management, and the Ecosystem approach	Various approaches to managing whole landscapes sustainably, with participation by all stakeholders. Features long-term outcomes are bringing together economic, ecological, and social concerns. It covers single agricultural practices up to regional planning and covers both land and water resources.	(CBD, 2004; Reed et al., 2017; Rollason et al., 2018)
Agroforestry, including silvo-arable, silvopasture and agro-silvo-pastoral	The practice of planting trees on farmland, including as rows between crops or as a shelter for livestock.	(Torralba et al., 2016)
Agroecology, conservation agriculture, and organic agriculture	Various approaches toward sustainable agriculture aim to protect ecological health and safeguard biodiversity. It focuses on the relationships between all types of organisms and the physical environment, hence a clear link to nature. There are different approaches or levels (of agroecology) from incremental to transformative. The exclusion of most synthetic fertilizers and pesticides is the most prominent distinguishing feature, while explicitly putting nature to work is its most functional feature.	(Warren-Thomas et al., 2018)
Forest and landscape restoration (FLR)	A process that aims to regain ecological integrity and enhance human wellbeing in a deforested or degraded forest landscape.	(Maginnis and Jackson, 2012)
Food forests, forest gardening	Have a stronger forest component aiming to harvest tree products intensively from such multi-species forests. It is a low-maintenance practice for plant-based food production. It relates to agroforestry practices.	Project Food Forest (Project Food Forest, 2016)

Natural climate solutions (NCS) or Nature-based Climate Solutions (NbCS)	Conservation and management actions reduce greenhouse gas (GHG) emissions from ecosystems and harness their potential to store carbon.	Griscom et al. (2017)
Sustainable practices	Primarily for production purposes, including natural nutrient and microclimate management. Anticipated benefits to people include more diverse and/or higher production quality, more stable productivity, safeguarded livelihoods and reduced damage by temperature stress.	Simelton, et al. (Simelton et al., 2021)
Amelioration and regenerative agriculture	Primarily for restoration of conditions for plants, water, soil, or air and climate change mitigation, e.g., bio- and phytoremediation.	Simelton, et al. (Simelton et al., 2021)
	Improve the health of soil or restore highly degraded soil, which symbiotically enhances the quality of water, vegetation, and land productivity. It typically employs techniques that are used more generally in organic agriculture.	Rhodes (Rhodes, 2017)
Nature-inclusive agriculture	It is a Dutch concept and term that has been literally translated into English. It is about working with and caring for nature with a focus on farmland biodiversity, namely using functional biodiversity and finally reducing environmental impacts.	Westerink et al. (Westerink et al., 2021)
Nature-positive agriculture (NPF)	It is a participatory, flexible, rapid response solution for helping small farmers halt ecosystem conversion and maintain High Conservation Values in line with company commitments and policies. NPF is most applicable to producers who are on conversion frontiers and are not certified under a sustainability scheme or management units. It can be adapted to any agricultural commodity and in various regions.	HCV Network ("Nature Positive Farming: a win-win for smallholders and nature," 2021)
Negative emission farming	It involves increasing sinks (photosynthesis and soil C sequestration) and reducing emission sources of a farm operation to spare land for nature.	Lal (Lal, 2021)
Permaculture	Permaculture is the conscious design and maintenance of agriculturally productive ecosystems with natural ecosystems' diversity, stability, and resilience. It is the harmonious integration of landscape and people providing their food, energy, shelter, and other material and non-material needs in a sustainable way.	(Ferguson and Lovell, 2014)
Circular agriculture	Focuses on using minimal amounts of external inputs, closing nutrients loops, regenerating soils, and minimizing the impact on the environment. If practiced on a wide scale, circular agriculture can reduce resource requirements and the ecological footprint of agriculture. It can also help ensure a reduction in land use, chemical fertilizers, and waste, which makes it possible to reduce global CO_2 emissions.	(United Nations, 2021)

2.3. Reflections on nature-based solutions definitions, principles and concepts

The definition of NbS from the EC can be used under European and Dutch contexts as it is mostly used on research and European Union (EU) policy. On the other hand, it is suggested to use the IUCN's and UNEA's definitions, since they are applicable for the European context but mainly for a more international approach. The IUCN's and UNEA's definitions can be applied indistinctively for the global north and for the global south contexts. Based on the literature review, the EC and IUCN definitions have been used for academic research, for policy purposes and for decision-making, while the WWF and the WB definitions are less used or not quite applicable for the food system. The UNEA's definition has been recently adopted (March 2022) with the aim to encourage Member States to integrate environmental considerations in their policy agenda. However, the preference for one definition over another is often related to the purpose and context of the user.

NbS approach is to address environmental and societal challenges by working with nature using different types of measures and interventions that also support socio-cultural values. NbS principles should embrace nature protection, rehabilitation and management but not all the interventions could be considered NbS, because not every NbS can be implemented everywhere (e.g., due to local climate, soil conditions, spatial diversity in types of farming, etc.) or could even generate maladaptation and disservices. Nevertheless, different site-specific "solutions" could be complemented and implemented alongside other interventions. This, with the aim to offer societal benefits, enhance social justice, maintain biodiversity and its ability to provide ecosystem services. In the agri-food context, NbS can help to achieve multiple societal goals like improving food production, increase biodiversity, and reduce vulnerability to climate change.

The types of NbS (intrinsic NbS, inspired NbS, and hybrid NBS), are in line with the European Commission (EC) definition and were adapted for agriculture and food system applications. Besides the wide overarching definitions and types of NbS, researchers, organizations, practitioners and decision-makers have adapted previous concepts (CSA, Agroecology, etc.) and new (NbS) concepts to deal with specific forms of agricultural practices and with climate change. Likewise, there has been grouped different agricultural and food system terms that fall under the NbS umbrella which enable their design and implementation. Most of the related NbS terms introduced above, deal in practice with activities or measures that cope with environmental issues, climate change, biodiversity, water and land management related to farming. As well, these terms and concepts can be applied at a landscape scale and rural areas for food production varying from intrinsic, inspired or hybrid NbS.

At this point, it can be stated that NbS is to date a less widespread concept in agriculture and food systems and is currently relatively more discussed in relation to urban environments. The use of NbS as a concept in the agri-food sector has roots in biodiversity management and conservation, disaster prevention at a landscape level, and is as a tendency more used by people and organisations with an environmental conservation background or perspective.

3. Nature-based solutions for food security and circularity under climate change conditions

Worldwide increasing challenges -such as climate change jeopardizing food security, water resource provision, and enhancing disaster risk- must be solved. Awareness of the value of nature in addressing environmental, social, and economic challenges is growing. NbS are increasingly prominent in climate change policy, and their adaptation concepts are being promoted worldwide because of their cost-effectiveness, multi-benefits, and wide applications. NbS has been described as an effective practical mean to handle and reverse global environmental issues such as biodiversity loss, ecological restoration, and natural resources degradation (Cohen-Shacham et al., 2019) based on a set of best practice principles concerning climate change, disaster risk, water security, food security, human health, and socio-economic development.

Opportunities and knowledge products of NbS have opened up a portfolio of NbS measures, which can offer efficient scopes for addressing conservation, climate, and socio-economic factors by maintaining healthy and productive agricultural systems, especially at the risk of adverse climate change scenarios (Miralles-Wilhelm, 2021).

Identifying and implementing robust climate change adaptation measures in the food system that is low-cost and resilient is critical, especially for the unfold-future, as there are only projections to represent climate change, though the exact events are still unknown. The prevailing approaches have involved a mix of direct (e.g. irrigation) and indirect (e.g. early warning systems) adaptation interventions worldwide (Enríquez-de-Salamanca et al., 2017). However, there is a widespread recognition that NbS can complement these approaches in rural and urban contexts (Adapt, 2019; Hobbie and Grimm, 2020).

NbS can be applied to the conservation and sustainable use of natural resources in conjunction with ecosystem protection, multi-functionality, and sustainability of ecosystems. It can be involved in designing and managing new ecosystems (European Commission, 2018). Especially, NbS for water management and food security constitutes a new paradigm that uses ecosystem services to enhance water quality and quantity of agricultural production while preserving the integrity of ecosystems (Sonneveld et al., 2021). In agriculture, NbS can be applied to various parts of agriculture, such as soil health, carbon sequestration, low-emission farming practices, enhancing crop productivity through increasing water/nutrient use efficiency, and low-emission supply chains. NbS is a key factor in attaining net-zero emission goals while adapting to climate change and achieving food and water security.

Various farming systems across Europe and in the global south use NbS. A key principle is that ecologically based diversification reduces vulnerability to hazards while at the same time it can increase productivity. Examples are (see Figure 2) integrated crop-livestock systems, soil organic matter management, mixed cropping, crop rotations, biological control of pests and agroforestry. Resilience to climate disasters is closely linked to farms with increased levels of biodiversity. An agro-ecological approach supports biodiversity, which has growing importance in the global debate on NbS and agri-food systems (EEA, 2021).

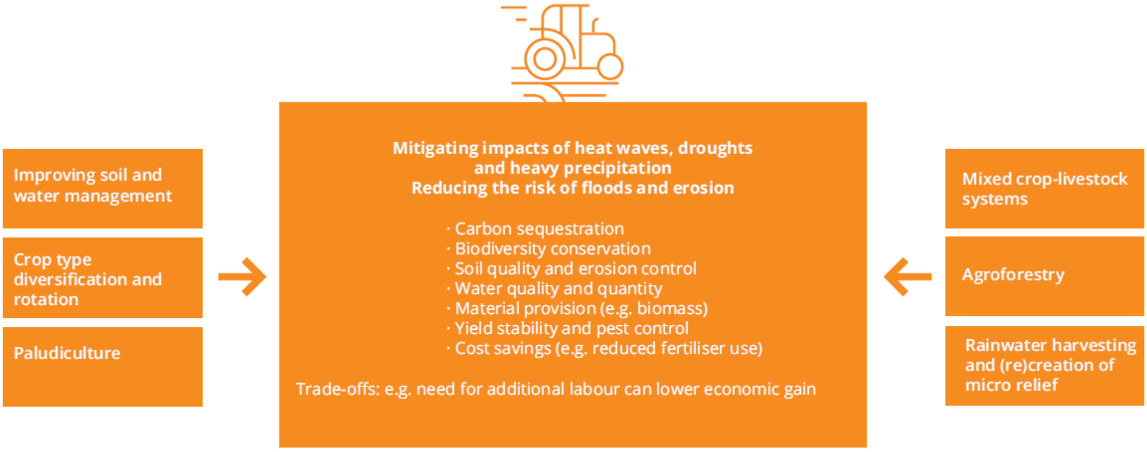

FIGURE 2. KEY NATURE-BASED SOLUTIONS FOR ADDRESSING CLIMATE CHANGE IMPACTS ON AGRICULTURE, THEIR BENEFITS AND TRADE-OFFS (SOURCE: EEA, 2021).

3.1. Food security and nature-based solutions

The ongoing effects of climate change on the agricultural sector impact food production and peoples' livelihoods and compromise food security at both global and regional levels. NbS measures that conserve or improve nature often have dual effects of emissions reduction and increasing resilience, delivering benefits for mitigation and adaptation to climate change (Köberle et al., 2022). NbS seek to maximize the ability of nature to provide ecosystem services that help address climate change adaptation measures in food security.

Figure 3 explains the paradigm shift in human-animal-soil-plant components from the 18th century. Early agriculture was more stable with a more vital link between soil–plant, animal, and human components involving the two-way transfer of nutrients. However, with urbanization, industrialization and specialization of agriculture, the connections between the components have become weaker due to less use of animal and human-based natural products (Mrunalini et al., 2022). Therefore, NbS measures require recovering two-way transfer of nutrients in the soil–plant, animal, and human components.

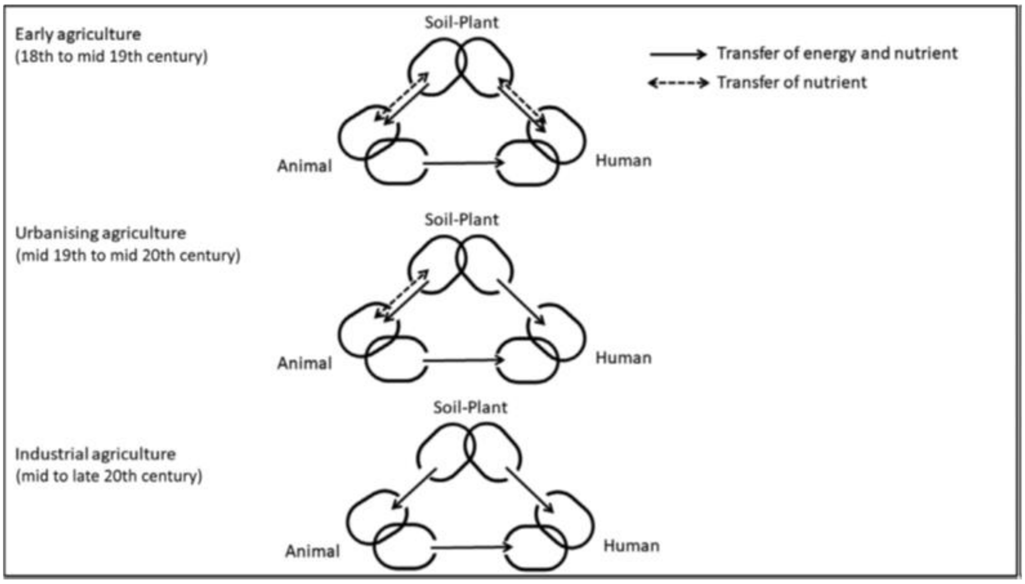

FIGURE 3. SCHEMATIC DIAGRAM DEPICTING THE PARADIGM SHIFTS IN AGRICULTURE. (SOURCE: MRUNALINI ET AL., 2022).

NbS towards developing sustainable food systems and food security regarding climate change can be divided into two main groups of strategies: soil solutions and landscape solutions. Soil solutions aim to enhance soil health and soil functions through which local ecosystem services will be maintained or restored, and landscape solutions mainly focus on connectivity (Keesstra et al., 2016).

Simelton et al. (Simelton et al. 2021) developed an NbS framework (see Figure 4) demonstrating various typologies and their essential primary function. These primary functions have focused on the multiple areas where there is a scope for NbS in achieving ecological sustainability in food systems and food/water security in climate change scenarios.

The following focus areas and contributory mechanism of the NbS framework (Simelton et al., 2021) are defined as follows:

- **Production:** Sustain or increase agricultural production by means other than standard approaches to the availability of water or nutrients or plant breeding.
- **Nutrients:** Retain or increase available nutrients in the soil, water, and plants, in plant-or animal-available forms.
- **Microclimate:** Improve microclimate at the soil surface or in the cropping zone by beneficial regulation of any combination of moisture, humidity, air movement, or temperature.
- **Water flows:** Regulate water flows (energy, rate, or volume) on soil surfaces, in soil masses, and at water body peripheries.
- **Soil erosion:** Prevent soil erosion by armoring a slope or watercourse bank or by catching eroding material (safeguard topsoil quantity).
- **Slope stability:** Enhance slope stability against shallow mass failures by roots or other natural products, increasing soil shear resistance, anchoring through failure planes, and supporting soil masses by buttressing and arching (safeguard soil masses).

- **Pollutants:** Remove, degrade or contain contaminants in water, soil, or air through any one or combination of natural physical, chemical, or biological agents (bio and phytoremediation).
- **Biota:** Restore or stimulate beneficial biota for soil health, pollination, or pest control, in the soil, cropping zone, or nearby environment.
- **Carbon sequestration:** Remove or store atmospheric carbon in soils or plants.
- **Biological diversity:** Increase or protect biological diversity and habitat, either wild or modified.
- **Connectivity:** Enhance connectivity, area, or the health of ecosystems.

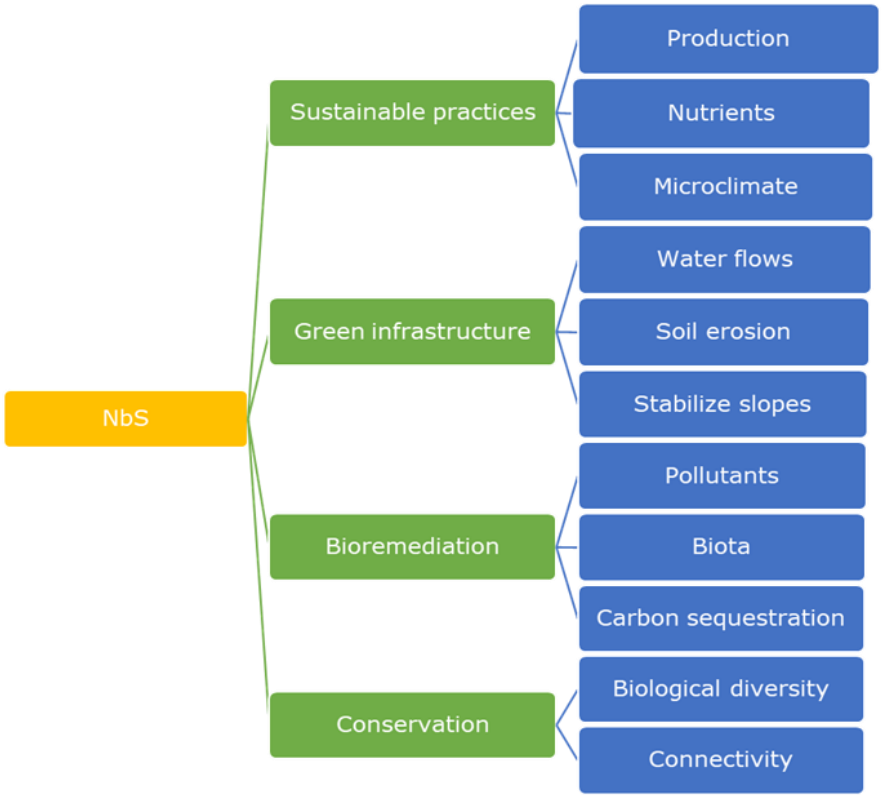

Figure 4. The NbS framework for agricultural landscapes (Source: Simelton et al., 2021).

A quick literature review on some NbS benefits and co-benefits for food security under the context of climate change was developed. Ecosystem services are strengthened by adopting NbS, such as sequestering carbon in soil and vegetation, improving renewability and quality of water resources, maintaining biodiversity, and adopting nutrition-sensitive agricultural practices (Lal, 2022). There is also evidence of NbS in reducing soil and water losses in agriculture, where different strategies were used, such as mulches, geotextiles, cover crops, catch crops, chipped branches, no-tillage, or terraces (Keesstra et al., 2016; Mandal et al., 2017; Prosdocimi et al., 2016).

The European Environment Agency report (EEA, 2021) mentions relevant NbS benefits and co-benefits for agriculture and food security under a climate change context:

- **Agroforestry:** The multiple benefits of agroforestry systems include higher carbon sequestration and higher biodiversity levels than conventional agricultural systems (but lower than that of many natural forests), and they enable wildlife corridors and protect livestock. Economically, by their nature, agroforestry systems increase economic resilience because they are a means of reducing reliance on a single source of income. Agroforestry systems are also proven to substantially contribute to climate change adaptation and reducing threats.

- **Conservation agriculture**: It promotes minimum soil disturbance (see also minimum tillage), maintenance of permanent soil cover and biodiversity. This leads to an improved soil structure, reduced use of fertilizers and lower CO_2 emissions. Such practices improve the ability of crops to adapt to climate change and variability, and they can perform as well as high-input systems.
- **Mulching and use of cover crops:** Cover crops (grass or legumes in rotation between regular crops) can help alleviate drought stress by increasing water infiltration rates and soil moisture. They can also improve soil quality by increasing soil organic matter and reducing erosion. Cover crops help reduce the effects of extreme radiation, extreme rainfall and strong winds. Cover crops can also lead to savings in input costs by adding or recovering nutrients and can generate revenue when sold as biofuel feedstocks. Cover crops can have both positive and negative impacts on yields, but they help to promote the long-term sustainability of the farm, even if the immediate net returns are not positive. Mulching has similar effects through coverage of the soil and feeding the soil at its surface. It suppresses the growth of unwanted plants. There is no competition with the main crop for nutrients and water.
- **Minimum tillage:** No tillage or minimum tillage contributes to more productive soils, as carbon storage in the upper soil layers can increase. No-tillage may be viewed as a method for reducing soil erosion and ensuring food security, while an increase in soil organic carbon storage is a co-benefit for society. In general, there are uncertainties over the effectiveness of this option, and its suitability depends on soil type, as some soils do not respond well (e.g., heavy clay). No-tillage can also lead to the increasing use of pesticides or alternative forms of pest control.
- **Crop diversification and rotation:** Diversification of crop varieties can ensure crops' resistance to extreme weather events. Diversification strategies can include mixed cultivation, intercropping and maintaining the local genetic diversity of crops to spread risks. Diverse systems are more resilient to natural disasters than monocultures and exhibit greater yield stability.
- **Paludiculture:** It is a 'wet agriculture' practice on peatlands for producing biomass, for example, for bioenergy or building materials. Across the EU, drained peatlands comprise 2.5 % of agricultural land but are responsible for 25 % of agricultural greenhouse gas emissions. Wet peatlands do not release CO_2, can sequester carbon, help to improve water quality, provide habitat for rare and threatened species and can be used to produce biomass in paludiculture. Therefore, restoring peatlands and implementing paludiculture benefits both climate change mitigation (less greenhouse gas emissions) and adaptation (reduced risks of floods as well as droughts), and it increases biodiversity compared with conventional agriculture.

- **Mixed crop-livestock systems:** They can use resources more efficiently by using crops and grassland to feed animals and fertilize fields with their manure. In this way, mixed crop-livestock systems improve nutrient cycling while reducing chemical inputs. Mixed-crop livestock farms have improved environmental performance but may have drawbacks, including increased workload and reduced productivity and economic performance.
- **(Rain)water harvesting and (re)creation of micro-relief:** It increases the resilience of a farm to water scarcity and droughts. It offers a promising contribution to enhancing the availability and quality of water. For rainfed crops, rainwater harvesting increases production per unit of area and input. Improved rainwater harvesting and storage can also result in energy savings. Water harvesting can be implemented at various scales: rainwater harvesting on the farm, construction of floodplains near agricultural land and groundwater recharge in dry areas. Rainwater harvesting can reduce groundwater levels and stream flows, but farmers can incur high costs.

3.2. Nature-based solutions and circularity

The linear economic model "take-make-use-waste" that has taken place in the last decades is considered responsible for the current climate crisis because our current consumption rate exceeds by far the planet's resources and the planetary boundaries. There are enough raw materials for food, shelter, heating and other necessities; our economy must become circular to ensure the same in the future. That means preventing waste by making products and materials more efficiently and reusing them. If new raw materials are needed, they must be obtained sustainably so that the natural and human environment is not damaged (Government of the Netherlands, 2017)

Circular agriculture is explained by many researchers (Berkhout et al., 2019; Keesstra et al., 2020) as a reduction of resource consumption and emissions to the environment by closing the loop of materials and substances. Losses of materials and substances are minimized, prevented, and recovered by reuse, remanufacturing and recycling. In line with these principles, circular agriculture implies searching for practices and technologies that minimize the input of finite resources, encourage the use of regenerative ones, prevent the leakage of natural resources (e.g., carbon, nitrogen, phosphorus, water) from the system, and stimulate the reuse and recycling of inevitable resource losses in a way that adds the highest possible value to the system.

In the agricultural sector, NbS is proposed as 'the use of natural processes or elements to improve ecosystem functions of environments and landscapes affected by agricultural practices and to enhance livelihoods (Simelton et al., 2021). NbS play an important role in 'keeping resources in use'; this can be done by recovering and reusing water, biomass and by-products to produce valuable new products and giving new applications to waste materials generated (Stefanakis et al., 2021).

Circular management of resources in ecosystems is crucial for addressing global environmental problems. NbS use nature comprehension and examples to solve environmental problems like waste and residue management at different levels. Some examples of NbS applied to the circularity concept at different levels are discussed in Box 1.

Box 1. Examples of Nature-based solutions for circularity and food security

Photo ©

Case 1. The use of mushrooms as a degradation mechanism

Mushroom consumption has become a tradition among many people due to its richness in flavours and proteins and is appreciated due to its low calorific value and nutritional value. On top of that, mushrooms act as a good decomposer as they degrade cellulose and lignin of plants and other waste and residues for their growth. This made them of interest for use in the field of biodegradation and bioremediation. Additionally, mushrooms can act as accumulators of some macronutrients, like phosphorus (P) and potassium (K) (Malinowski et al., 2021), and can also maintain soil health by performing the role of hyperaccumulators of metals. Some companies working behind this idea are Rotterzwam (in the Netherlands), using an urban approach, and Pilze Nagy (in Hungary), with a more rural approach.

Rotterzwam is located in the city of Rotterdam, and the company collects coffee grounds from local pubs, large corporations and restaurants. Coffee residues are a fertile substrate for growing oyster mushrooms. They mix coffee husks and mushroom spawn to grow oyster mushrooms. The mushrooms are sold to local restaurants and shops in the city. The entire process is sustainable and local, an outstanding example of an urban NbS used towards a circular economy.

On the other hand, Pilze-Nagy Kft, located in the North of Kecskemét in Hungary, uses biomass side streams of agriculture and forestry to produce marketed innovative and wider-scale products. The side streams are converted into a substrate for oyster mushrooms. The company also grows and distributes oyster mushrooms in the wholesale and retail market. The mushroom production is fully free of chemicals and in compliance with the conditions and terms of bio-mushroom production, and officially certified. This solution is taken as an example of Hungarian secondary biomass valorization. The resulting waste from mushroom production is also used to produce biogas and electricity.

Link: Pilze-Nagy Kft, Oyster mushroom production: http://pleurotus.hu/en#b3

Photo ©

Case 2. The use of insects as feed

The idea behind it is that in nature, many species of animals eat insects, like wild birds, trout and salmon. This idea was taken by several companies (such as Bestico B.V.) to provide a natural diet to farmed animals like chicken and fish.

Bestico focuses on producing the Black Soldier Fly larvae because of its nutritional value, speed of growing cycle and because it can handle a variety of residues. Issues like protein shortages for animals and underutilization of industrial by-products and leftover food are tackled with this application. Insects contain a lot of protein and eat food waste (like potato peels) and agricultural waste. This concept can be operated in rural areas where wet starch/protein residue streams become available. The protein-rich product is very suitable for aquaculture, poultry and pet food (Liu & Koppert, 2018).

Link: EIT Food, Food Unfolded. How flies make farming more sustainable:
https://www.foodunfolded.com/article/how-flies-can-make-farming-more-sustainable

Photo ©

Case 3. Seashells waste reutilization

Dumping seashell waste has multiple side effects from the perspective of environmental, hygienic, social, and financial dimensions; therefore, we need to pay more attention to seashell recycling from the beginning of shellfish production. It is reported that these residues can contribute to increasing circularity and/or improve the natural environment for food systems.

Recycling of seashells to re-establish mussel and oyster reefs and is a practice that has been taking place in several places around the globe like Australia, New York, Thailand. Small marine organisms and larvae use the reef for their shelter. The loss of this habitat causes losses in the ecosystems and affects fish populations and food supply. Kuykendall et al. (Kuykendall et al., 2015) suggest the use of seashells as material for building artificial reefs for oyster or mussels' recruitment. This application also helps to mitigate coastal erosion and to enhance soil strength.

Oysters and shellfish are also excellent water filters; the removal of these species has caused a decline in the quality and turbidity of the seawater. Additionally, the use of oyster shell residues as filter media for the fishpond system has been reported. Oyster shells have a good stabilizing effect on the pH value. However, this utilization of waste shells is still on a small scale, and none of the processes is advanced enough to be commercialized (Chilakala et al., 2019; Wakefield, 2020).

Link: GDP Industries, Restoring Southern Australian reefs with recycled seashells: https://gdp-industries.org.au/restoring-southern-australian-reefs-with-recycled-seashells/

Photo ©

Case 4. Herbal teas that restore biodiversity

Dutch farmers manage over 65% of the land area. Biodiversity is under pressure in the Netherlands and has declined significantly in recent decades. Many pastures in the country are in bad shape from an environmental perspective. Only one type of grass is growing, usually ryegrass. Biodiversity is poor in these meadows. Improving biodiversity in the Netherlands can be made possible if the government and private sector work together with farmers. Wilder Land sows herbs and spices on the edges of farmers' fields and meadows to create new opportunities for life, such as bees and butterflies. In this way, they restore biodiversity in the Netherlands together with farmers without the use of pesticides.

A part of the herbs they sow is harvested to make tea. The rest, at least half, is left so that the insects can continue to enjoy them. Then, after the flowering period, the wind takes over and spreads the seeds across the land. Thus, in the following spring, herbs will emerge in even more places. Slowly, nature takes over again – is the vision of the company. With the production of Dutch herbal tea, they create a new revenue model for farmers who want to contribute to more biodiversity. Wilder Land is working with farmers to encourage biodiversity. With the sowing of more native herbs or (un)herbs, they get more healthy pastures and fields. The flowers of these herbs, in turn, attract insects that are needed for pollinating crops. It is very important to have these natural pollinators for food security (Matthijs & Daan, 2019).

Link (in Dutch): Wilder Land makes herbal teas that restore Dutch biodiversity:
https://www.voordewereldvanmorgen.nl/leden/wilder-land

According to the European Waste Law (European Commission, 2007), waste is essentially a "discarded material". This means that if a material has potential for further use in the economy, it should not be considered a waste. Unfortunately, definitions as a by-product, residues or secondary raw material have no legal meaning in the European Waste Law, and materials are simply waste or not. Considering this legal definition, all residues used as feedstocks in systems, like the examples of Box 1 previously mentioned, should not be classified as waste.

This type of limitation has already affected one of the cases described. Rotterzwam had to deal with legal issues. Coffee grounds were officially classified as waste and could not just be used in agricultural applications. Rotterzwam was looking for the reclassification of the material as "continued use" by submitting a request to the DCMR Milieudienst Rijnmond to use coffee grounds as a substrate for the cultivation of oyster mushrooms. In June 2021, Rotterzwam received the ruling from DCMR concluding that the use of coffee grounds can be regarded as continued use (Cox, 2021; "WUR and Rotterzwam studying the effects of used coffee grounds on the soil," 2019).

3.3. Reflections on nature-based solutions for food security and circularity under climate change conditions

NbS could be seen as cost-effective interventions (Ditzler et al., 2021) to adapt agriculture in a changing climate, as well as measures to enhance resilience and food security while protecting the environment. Agricultural producers play a key role in the implementation of NbS. However, this concept has not been well introduced yet to farmers and other stakeholders, creating some resistance or hesitation in their applications for food production.

The European Union (EU) and global climate change policies are enabling the design, planning and implementation of NbS through some laws and regulations, economic and financial incentives, and capacity building, but more efforts need to be made for a bigger uptake of NbS in the food system.

NbS for food production has been adopted with single interventions but as well in conjunction with other types of measures to achieve food security, environmental protection, restore biodiversity and address societal challenges and climate change targets. NbS for food security has been proven to bring farmers and agricultural producers certain benefits through diversified production systems and sources of income.

NbS in food systems is helping to adapt better to climate hazards like droughts, heavy rainfalls, flooding, enhancing soil health, and enhancing water quality and quantity. NbS can reduce CO2 emissions from the food sector and even store carbon. Likewise, some NbS increase habitat diversity in terrestrial and aquatic ecosystems. As Sumberg (Sumberg, 2022) states, from an agronomic perspective, many of the NbS and their benefits have been known for decades and have proved to be useful in particular contexts. The agricultural (good) practices we mention here, as well as the circularity and recycling paradigms, are core techniques and values of organic and agroecological farming.

Conceptualizing those as NbS could be a mean to transport and spread those to new user groups. In doing so, drawing on existing users and their experience is certainly beneficial. Agroecology, for instance, focuses on the farmer and the farm as a whole (see Table 1) and develops consistent systems. NbS is partly conceptualized as a more landscape-related process where promoting single measures may make sense as focussing on a larger number of individuals. Hence, a difference in entry points, goals, stakeholders and who leads or initiates such process.

Circular food systems aim to optimize the use of resources and reduce food losses through the efficient use of land and closing the water, nutrient and carbon cycles to minimize resource loss and environmental degradation. Thus, the use of NbS for food production could encourage the use of regenerative resources and add value to the food system.

Circularity in food systems also implies changes in consumer behaviour and governance structures. Circular agriculture is a term commonly used in the Netherlands. However, organic farming has been globally used as the prototype of (re)cycling materials since this is one of its central features. It is important to clarify that circular agriculture is not per se organic farming nor necessarily is adopting a broad spectrum of NbS. In any case, channelling resources as long as possible at a relatively high energy level has the clear potential to benefit both farmers and nature.

4. Drivers, opportunities and hindering factors for successful implementation of nature-based solutions

The different abovementioned NbS examples at different scales for food production are a good indication that decisions and public-private investments have been made to foster NbS. Thus, it is relevant to know which are the drivers, opportunities and hindering factors during the design, planning and implementation processes of such measures and if the potential benefits and co-benefits of NbS to multiple stakeholders could be justified as a low-regret option for investments.

4.1. Drivers and opportunities

Climate change is one of the most important drivers identified for the design, planning and implementation of NbS in the agri-food sector. According to FAO (FAO, 2021a), it is important that policymakers, researchers, and practitioners join efforts to harness the full potential of NbS for enhancing countries' climate ambition and helping them to achieve their national climate targets in a more inclusive, green, and effective manner. As well, there is more interest for public and private investors, motivated by Climate Agreements, and Nationally Determined Contributions (NDC), National Climate Adaptation Strategies (NAS) and Sustainable Development Goals (SDGs) to provide funding for NbS implementation in agriculture (EEA, 2021; FAO, 2021a).

NbS is currently enjoying the political "momentum" to mobilize more ecological sound systems to address urgent environmental problems (e.g., excessive nitrogen and CO_2 emissions, biodiversity loss, ecosystem degradation). Likewise, this NbS momentum is facilitating a transition of society and from different sectors, including the agri-food sector, to accelerate the adoption of NbS in sustainable cropping, fisheries, and livestock practices through strategic public interventions private investments, and corporate leadership (FAO, 2021a).

The biodiversity crisis has been seen as well as an important NbS driver in the agri-food sector. The Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the European Commission, in its ambitious European Green Deal, recognize the need to foster NbS and Ecosystem-based approaches as means to halt the rapid biodiversity loss directly and indirectly caused by unsustainable agricultural practices (EEA, 2021).

Farmers are great drivers of NbS as they can combine their traditional knowledge with new skills to safeguard the ecosystems on which our food production depends. Farmers, ranchers, and food producers are important stewards of the ecosystem and of climate change and play an important role in developing and implementing environmental and agriculture solutions. Participation and the inclusion of stakeholders' perspectives from an early stage of the design of NbS and for funding schemes are fundamental not only for ensuring their effectiveness in delivering multiple benefits but also for ensuring their public acceptance. NbS need to be designed in an inclusive and equitable way to ensure their successful implementation and the delivery of multiple benefits for a diverse range of societal objectives (EEA, 2021; FAO, 2021a).

In terms of opportunities, policies have begun to reflect the growing recognition that, while ecosystems and their services are vulnerable to climate change, they can also serve to protect society from climate change impacts. The global and EU policies reviewed by the European Environment Agency (EEA, 2021) had almost equal numbers of policies providing medium or strong explicit support for NbS, even though they used different key terms. Concepts and terms such as ecosystem-based approach, agroecology, agroforestry, organic agriculture, and blue-green infrastructure, among others (previously explained in section 2), are most frequently used.

Even though there is still a slow recognition, NbS has a strong political potential in the agri-food sector. However, the type of support varies widely in practice and leaves important gaps, which will be explained in the hinder factors section (EEA, 2021).

For monitoring and evaluating NbS, currently, there exist fragmented indicators that have the potential to be streamlined to encourage more effective design and implementation of NbS in agriculture. Likewise, such indicators could bring opportunities to help understand and value the co-benefits of NbS and their trade-offs. Monitoring and evaluation indicators for NbS are beneficial to gaining the support of multiple stakeholders in the design and implementation of NbS. For instance, the International Union for Conservation of Nature (IUCN) launched the "IUCN Global standard for nature-based solutions" at a high-level virtual event in 2020. This standard includes guidance (with eight criteria and 28 indicators) and a self-assessment tool. It also provides a common understanding and consensus on NbS to accelerate the scaling up of proven and workable models of NbS (EEA, 2021).

European Union (EU) funding and initiatives towards a green recovery are the main drivers and have the potential to encourage the use of NbS as a mean to achieve sustainability, biodiversity and climate-related objectives in parallel, for example, the EU biodiversity strategy for 2030 and the European Green Deal. Sustainable finance is a key to channeling public and private investments towards a sustainable, climate-resilient economy. Existing policies like the Common Agricultural Policy (CAP) and the Land use, land use change and forestry (LULUCF) can strengthen the baseline requirements for spending and dedicate increased funds to rural development plans to increase the uptake of nature-based farming practices (e.g. agro-ecological agronomic practices and agroforestry), green infrastructure (e.g. hedgerows, buffer strips, fallow land, extensive pasture) and biodiversity-friendly practices (EEA, 2021).

4.2. Hindering factors

At both EU and global levels, persistent weakness in NbS policy frameworks is the lack of coherence among policies and fragmented governance arrangements. This can challenge the collaboration, synergies and degree of joint financing across multiple agendas. Further alignment of sectoral planning instruments and mainstreaming of NbS in agriculture is needed to reduce the burden of conflicting requirements and facilitate cross-sectoral collaboration for implementing multifunctional solutions. At the EU and global levels, there still exist shortcomings in the design and implementation of policies that support NbS. As adopting conducive national and local policies is central to facilitating the uptake of NbS, the lack of EU and global requirements for mainstreaming NbS and monitoring its implementation is a critical gap (EEA, 2021).

Several factors limit the effectiveness of NbS for agriculture and may even put them at risk. Despite potential positive effects, diversification measures are not always implemented because of a lack of the required investment, expertise and research evidence (EEA, 2021). Some examples are:

- A barrier to introducing mixed crop-livestock systems is low short-term profitability at the farm level.
- Major barriers to crop diversification are related to a lack of technical knowledge and references and to a lack of crop varieties adapted to the local context, and fears of increased complexity.
- A lack of proper community and stakeholder involvement can act as a barrier.

Vermunt et al. (Vermunt et al. 2022) identified five key blocking mechanisms that hinder the adoption of NbS (nature-inclusive agriculture-NIA) in the Dutch dairy sector. These five barriers are partly interconnected but show a range of systemic barriers that apply to multiple agricultural sectors in the food system.

The first hindering factor is the insufficient economic incentives for farmers. The second one is the limited action perspective of many dairy farmers in the Netherlands. The third hindering factor is the lack of a concrete and shared vision for NbS. The fourth aspect is the lack of NbS-specific and integral knowledge. The fifth one is regime resistance, which moreover is connected to each of the previous blocking mechanisms (Vermunt et al., 2022).

In order to accelerate the adoption of NbS and nature-inclusive farming practices, problems need to be addressed in conjunction with one another, and therefore holistic approaches are key. Similarly, in order to foster the growth of the innovation system around NbS, the focus should not only be on innovation but also on transforming current regimes, in particular the currently dominant economic paradigms of growth and yield maximization (Vermunt et al., 2022).

Although there is increasing evidence of the success of NbS in agriculture, climate change and disaster risk reduction, quantifying their effectiveness in biophysical, social and economic terms is a complex task, and quantitative data are still scarce. Quantitative and measurable indicators for monitoring and evaluating the progress and effectiveness of NbS are lacking across policy arenas (EEA, 2021).

Han and Kuhlicke (Han and Kuhlicke, 2021) also identified other barriers to NbS, such as the difficulty of monetizing ecosystem services. Therefore, the benefits that NbS could provide are hard to quantify and hinder making proper cost-benefit analysis to justify investments in NbS measures. Another hindering factor mentioned was the lack of knowledge on the maintenance of NbS. Thus, local knowledge can be key in fitting NbS for local problems but is often not considered or overlooked.

Agricultural governance is siloed, creating distance between policy on biodiversity and ecosystems and policy on food systems. This siloed approach hampers integral decision-making processes, which are essential for effective NbS uptake. Agricultural policy of the last decades has been focused on stimulating productivity growth of agricultural sectors (Erisman and Verhoeven, 2019) while at the same time inadequately dealing with externalities created by the intensifying agricultural sector, sparking outbursts of protest from the agricultural sector (van der Ploeg, 2020). The lack of (communal) vision from the regime and governance towards viable alternative practices enables regime efforts to keep the current capital-intensive and ever-expanding agro-economic system upright.

There are a lot of challenges in policy and governance while implementing NbS (Seddon et al., 2020). For example, NbS often involves multiple actions overbroad landscapes and seascapes, crossing jurisdictional boundaries. Effective management of storm-water drainage across watersheds using nature-based approaches requires joint decision-making across different local, regional, and national governments and multiple ministries (agriculture, forestry, and environment, finance, development, transport).

Another barrier is a lack of knowledge on the implementation and effects of NbS on both agricultural production and their ecological effects. The extent of this knowledge gap stretches from insufficient knowledge on the system level (relation between NbS and ecology, biodiversity, water systems) to education and training of (future) farmers (Vermunt et al., 2022)

Experiences from good practices are insufficiently shared within the agri-food sector, as many knowledge providers act commercially or are not independent of other actors in the regime. There is a lack of independent, not-for-profit NbS knowledge in the sector. Lack of available knowledge, combined with a strong focus on farming practices suiting the conventional agro regimes, results in insufficient NbS content in agricultural education and training (Vermunt et al., 2022).

The upfront costs and short-term risks, and uncertainty associated with a transition to nature-based agricultural practices pose a significant barrier to adoption. This is particularly the case for poor farmers, many of whom are women, who face significant resource constraints (including capital, land, access to fisheries, and labor) and frequently are unable to insure themselves against the risks of crop, livestock or fish production failure. For these farmers, the choice of which agricultural practices to adopt is inseparable from concerns over food security. Under these conditions, it is extremely difficult to take on the added costs and risks of transitioning to a new way of farming (FAO, 2021b).

An overarching barrier is a strong regime resistance. The agro-economical regime, especially in dairy farming, produces an extremely capital-intensive sector where individual farmers often do not have the financial means to take risks or finance a transition period. The influence of regime actors on education and training could propagate conventional farming practices at the cost of NbS (Vermunt et al., 2022).

Other financial aspects of the agricultural system that are a main limiting factor for NBS uptake are mentioned by (Farjon et al., 2018) and revolve around two principles. The first one is the added value (e.g., ecosystem services) that are not rewarded by premiums in the value chain. The second one is the negative external effects of conventional farming (e.g., water quality, biodiversity, health) that are not taxed or priced in the value chain or by governments.

Biodiversity and (aquatic) ecology are inherently complex issues; ecological effects of NbS implementation in agriculture are hard to assess ex-ante, as well as difficult to evaluate ex-post. Knowledge gaps on the ecosystem level, also outside the context of NbS-related research, further hamper the development and uptake of NbS. Knowledge development is hampered by a siloed approach in research and research policy and a lack of involvement of practitioners in research (Vermunt et al., 2022).

While NbS can help to mitigate the impacts of climate hazards in agriculture and provide benefits for adaptation, there are also limits to which ecosystems can cope with these hazards. Biodiversity is underpinning NbS, and therefore the effectiveness of such approaches is determined by the resilience of species and ecosystems to the impacts of climate- and weather-related hazards. Ongoing climate change might lead to more extreme climate- and weather-related hazards in agriculture that exceed the capacity of species and ecosystems to adapt, causing ecosystem degradation (EEA, 2021).

Furthermore, identifying and implementing adaptation measures such as NbS in agriculture requires long-term planning, which involves uncertainties and risks. There are, for example, uncertainties concerning future climate change impacts, the effectiveness of adaptation measures in the agri-food sector and societal needs (EEA, 2021).

The barriers to the widescale application of NbS that were identified in the Dutch setting of the dairy sector could also be present in other countries and food systems and, therefore, should be addressed as well. Varying between different global areas and food systems, the relative importance of certain barriers will shift case by case. This is illustrated in three worldwide examples in Box 2:

Box 2. NbS barriers identified in the international context

Barriers in Nicaragua, uptake of agroecology:

- Weak guidance and lack of vision
- Insufficient capacity or quantity of physical, financial and labor resources
- Lacking market development
- Knowledge exchange (mostly backed by international donors) does not consider existing local knowledge that could include NBS

In a case focused on the uptake of agroecological practices and NbS in Nicaragua, a notable barrier related to resources is the lack of not only financial and physical resources but also lack of personal resources for more labor-intensive NbS practices.
Another lesson from the Nicaragua perspective is the disappearance of local knowledge in knowledge exchange infrastructure caused by the dominance of international donor-backed knowledge exchange facilitation. In other countries, it has been shown that local knowledge can be the key to effective NbS **development** (Schiller et al., 2020).

Source:
Exploring barriers to the agroecological transition in Nicaragua: A Technological Innovation Systems Approach
Link: https://www.tandfonline.com/doi/full/10.1080/21683565.2019.1602097

Barriers in Jordan, upscaling of water harvesting: Lack of financial resources Lack of common vision in government Institutional problems (formal vs informal institutions regarding land tenure necessary for NBS) that inhibit the legitimization of NBS Aside from more general has seen barriers like lack of funding and lack of common vision from government institutes, a case in Jordan illustrates barriers originating from the contrast between formal institutions (e.g., governments) and informal (local) institutions regarding land tenure. The lack of legitimacy of informal institutions that are necessary to achieve spatial resources for water harvesting creates problems in NBS uptake. Similar patterns can be seen in other cases where grassroots NbS initiatives lack legitimacy (Sixt et al., 2018). **Source** *Transitions in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problems and blocking mechanisms in an emerging technological innovation system* **Link:** https://www.sciencedirect.com/science/article/pii/S146290111730816X?via%3Dihub
Barriers to Agri Innovation Systems (AIS) in New Zealand: Competitive science in silos Laissez-faire innovation (no uptake of innovation in SMEs because of lack of funding) Science-centered innovation (science works on innovations to obtain low-risk funding; projects promoting implementation are more high-risk and are not undertaken by research institutes) A reflection on science-driven innovation in agriculture in New Zealand shows not only the often-seen barriers created by a siloed approach in a field where a holistic approach is essential but also the drawbacks of a (too) heavily science-based innovation system. The innovation system lacks connection to agricultural practice, mostly caused by unintentional drivers related to the grant system and commercial workflow of the government-funded research institutes. Research is too competitive, resulting in siloed approaches. Research projects focused on knowledge innovation show a lower risk than projects directed at the practical implementation of innovations with entrepreneurs (that are lacking funding), resulting in hampered uptake (Turner et al., 2016). **Source:** *Systemic problems affecting co-innovation in the New Zealand Agricultural Innovation System: Identification of blocking mechanisms and underlying institutional logic* **Link:** https://www.tandfonline.com/doi/full/10.1016/j.njas.2015.12.001

The effectiveness of NbS depends not only on the specific intervention itself but also on the local context, including climatic, ecological and socio-economic factors and the vulnerability of rural communities and agri-food sectors to climate change and ecosystem degradation. In general, it is difficult to assess the effects of NbS and make comparisons because of unique local circumstances and the different combinations of options applied. In addition (quantified) evidence for the impacts is poorly documented in Europe and worldwide.

The feasibility of NbS and the trade-offs and potential negative consequences (so-called disservices) need to be assessed as well. For instance, the opportunity costs of land users can be considerable because of changes in management practices and the related loss of income sources. Some more engineered ecosystem-based adaptation measures may lead to a loss of or damage to natural habitats. The benefits of NbS may only occur after a considerable time (e.g. it may take decades for ecosystem restoration to deliver the desired benefits), and intended solutions may have negative consequences for some stakeholders (EEA, 2021).

Other benefits could be rainwater harvesting, as it can increase crop yield and improve resilience to water scarcity and droughts. It can result in energy savings because of the reduced need for pumping. As a trade-off, however, it can incur high costs for farmers and groundwater levels and lead to loss of (productive) land. Such disservices and trade-offs are highly context-dependent and are often not addressed when assessing the benefits of NbS (EEA, 2021).

4.3. Reflections on drivers, opportunities and hindering factors

As the European Environment Agency (EEA, 2021) report states, although current EU and global policy mixes provide a strong starting point, there are significant opportunities to strengthen the level of ambition and degree of support across sectoral policies to create new and optimize existing NbS for agriculture, climate change and disaster risk reduction and encourage innovation in this regard.

A broad uptake of NBS in food systems requires a thorough transformation of agri-economic systems. The transition to NbS, and one step earlier: the transition towards a holistic approach to agri-economic systems as food systems are currently driven by climate risks, a shift in the societal valuation of ecologically sound practices, and a pragmatic approach to problem-solving where NbS can be cost-effective solutions. However, hindering factors originate from knowledge gaps, institutional lack of vision, resistance from dominant regimes and financial aspects.

Lessons learnt from international studies on the uptake of NBS, or in a broader sense, innovation systems in agriculture, show that the required transition is not necessarily just by nature. Without proper attention to an inclusive approach, inequality and injustice will pose a risk. The vulnerable position of many (mostly SMEs, and not only in the global south) farmers originating from the dominant agri-economic buyer's market regime underlines the importance of a just transition[1] towards mainstreaming NbS.

The chosen approach to the required transition will determine the equitability of future food systems. Working with the current system as a pragmatic approach shows opportunities and potential for accelerated uptake when powerful market players and stakeholders adopt NbS and introduce them to the regime. However, this leaves current power relations in place.

The dominant regime in agro-economic systems has been identified as an overarching problem, hampering not only NbS uptake but also, in a broader sense limiting equitable positions of farmers, shared vision towards future food systems in the sector and ecologically sound practices. A more activistic approach towards a regime shift can take more effort from all parties involved but leaves space for evaluating power relations in food systems, enabling environmental justice for farmers facing climate risks, or farmers performing environmental services they do not personally profit from.

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[1] https://research.wur.nl/en/projects/1-1d-5-just-transition-kb-34-004-017

This dilemma has been studied in an urban context (Buijs et al., 2019; Raymond et al., 2021), highlighting the necessary assessment of social and cultural capital for initiating and maintaining NbS. This can be translated to the agricultural field by the importance of local knowledge, illustrated in the above Nicaragua case study. More generally stated: a transition towards mainstreaming NbS in food systems requires a thorough understanding of environmental and social justice in the current agri-economical regimes, mainly through procedural and recognition justice (the equitable access to resources, e.g., knowledge, government processes, funds). Moreover, the success of NbS implementation should be evaluated not only by measuring effects on risk reduction, productivity and economic benefit but also with indicators of justice effects. Here lies a knowledge gap: these indicators still need to be developed, not only for the food systems context but for all applications of Nature-based Solutions (Zafra-Calvo et al., 2020).

5.Nature-based solutions across various scales

The European Environment Agency (EEA) (EEA, 2021) report identified large- and small-scale NbS. According to the authors, the large-scale NbS are realized across landscapes and intersect with different ecosystems (e.g., rivers, floodplains, forests). These types of NbS require integrated planning strategies and strong collaboration between different actors (e.g., water basin authorities across provinces, regions, or countries). On the other hand, small-scale NbS are usually realized within a specific place (e.g., farm, plot level).

Some examples of large-scale NbS include the rehabilitation and restoration of rivers and floodplains (e.g., channel re-profiling, sediment dredging, changing the natural forms of rivers, extending floodplains) and the establishment and restoration of river buffers (i.e., strips of grass, shrubs, and trees adjacent to the river ecosystem). If established near agricultural areas, vegetation buffers along rivers can mitigate the run-off of pollutants from fields, improving water quality. The temporary flooding of agricultural land can act as a storage reservoir to capture peak flows during extreme rainfall events, avoiding flood damage downstream. Rainwater harvesting measures (e.g., ponds, swales, wetlands) are examples of small-scale NbS used in agricultural areas to mitigate flooding and water scarcity (EEA, 2021).

The geographical scale and context of a situation determine which type of NbS can be implemented and how local people perceive NbS. Consequently, the physical, socio-economic, and cultural scales are considered. When looking at the usability of the different types of NbS, it appears that intrinsic, inspired, and hybrid NbS can work differently at different scales. For instance, NbS types can be used from a small to a large scale ranging from a soil scale or a small plot of land to a landscape level or from an individual farm to an industrial or country scale. To illustrate this better, an intrinsic NbS on a soil scale would be enhancing measures such as soil health by increasing the soil organic matter content to increase climate resilience and increase green water availability and soil biodiversity (Garcia et al., 2018; Keesstra et al., 2021; Novara et al., 2019; Rodrigo ‐ Comino et al., 2020).

5.1. Examples of nature-based solutions at different scales and regions in food systems

In this section, we mention examples of the application of NbS in the Global South, Europe, and the Netherlands that contributes to agriculture, food production, climate change, biodiversity, societal challenges, and disaster risk reduction, among others. In Annex3, SI Figure 1, more international examples can be found.

5.1.1. Global South

5.1.1.1. Agroforestry

Agricultural systems use trees as a Nature-based solution to create optimal growing conditions and conserve biodiversity. Multiple examples of NbS planning exist, but not many on their application. For instance, there are plans or small initiatives to implement agroforestry activities like shade trees in coffee plantations in Honduras and trees for timber combined with annual crop production and animal husbandry in Indonesia. Trees provide shelter from climate extremes and diversify the incomes of farmers in Rwanda. Uganda uses trees for fuel and extractive industry. Peru has planned interventions for ecosystem restoration **(Dobie et al., 2020)**. Per definition, agroforestry covers more than one species on a given piece of land. By featuring at least two species, agroforestry systems are not perse biodiversity-positive. It still depends on the choice and mixture of chosen species.

Credit: Photo ©

Contribution: Sustainable landscapes, biodiversity, socio-economic challenges, and diversification of farming.

Scale: Large and small scale.

Location: Honduras, Indonesia, Peru, Rwanda, and Uganda.

Type of NbS: Hybrid.

Pros: Climate Change mitigation, soil health improvement, and surplus products.

Cons: More time consumption to benefit, occupies more land and reduces photosynthesis activity.

To know more:

Trees on farms as an NbS for biodiversity conservation in agricultural landscapes: https://www.worldagroforestry.org/publication/trees-farms-nature-based-solution-biodiversity-conservation-agricultural-landscapes

Trees in farms for biodiversity, Honduras: https://treesonfarmsforbiodiversity.com/honduras/

5.1.1.2. Mangroves

Protecting and creating mangroves areas can help protect coastal regions from flooding but also positively affect food security. Mangroves reduce saltwater intrusion, and by doing so, it keeps fresh water available in agricultural soils for rice or other production purposes. Furthermore, fish populations rely heavily on mangroves as spawning grounds. The fish catches of local fishers benefit from mangroves and therefore contribute to local food security **(*Financing the Earth's Assets: The Case for Mangroves*, 2020)**.

The Mangroves and Markets: Scaling up Ecosystem-Based Adaptation in the Mekong Delta project (MAM) supports mangrove restoration and protection in the Mekong Delta in Vietnam while strengthening the livelihoods and resilience of smallholder shrimp farmers and their families. Vietnam has lost half of its mangrove forests over the past 30 years, notably to make way for shrimp ponds. This is a worrying trend, as healthy mangroves contribute to climate change adaptation and mitigation. Mangroves act as a natural barrier against storms, sea level rise, and erosion and have a high potential to store and sequester carbon. In addition, the mangrove ecosystem forms a natural habitat for many aquatic and terrestrial species and provides a source of livelihood for coastal communities **(SNV, 2016)**.

SNV and the International Union for Conservation of Nature (IUCN) jointly developed the MAM project to reduce the pressure on mangrove forests. The project supports the development and introduction of sustainable aquaculture models which restore and protect mangrove forests while enhancing smallholder livelihoods and resilience. They aim to replicate and scale up the sustainable integrated mangrove-shrimp farming model along the coasts of Ca Mau, Ben Tre, and Tra Vinh provinces, which together contain half the mangroves in the Mekong Delta**.**

Credit: Photo ©

Contribution: Coastal protection, disaster risk reduction, food security, biodiversity, climate change, and socio-economic challenges.

Scale: Large and small scale.

Location: Vietnam.

Type of NbS: Intrinsic.

Pros: Coastal protection, source of seafood, and ecological diversification.

Cons: Increase in the insect population.

To know more:

SNV, Mangrove restoration- Scaling up Ecosystem-Based Adaptation in the Mekong Delta: https://snv.org/project/mam-ii-scaling-ecosystem-based-adaptation-mekong-delta

5.1.1.3. Rainwater harvesting

Water harvesting increases water security and contributes to productive farmland in rainfed systems **(Cooper, 2020)**. Several water harvesting methods exist and are being applied in different countries, like India, Kenya, and Ghana. Examples of water harvesting methods such as NBS are terraces, contour bunds, and buffer strips. Two nature-based solutions are having a high impact on Bono East Region's food system and Ghana: Rainwater harvesting for irrigation and forest landscape restoration in combination with food production. If implemented in conjunction, they lead to an increased water storage capacity of soils, enhanced water availability for food production, increased soil fertility, and increased yields. They enhance resilience against climate stress and contribute to circular land and water use **(Groot et al., 2020)**.

Credit: Photo ©

Contribution: water and land management, food security, climate change.

Scale: Large and small scale.

Location: Ghana.

Type of NbS: Intrinsic.

Pros: Decreasing drought vulnerability reduces groundwater demand.

Cons: Space requirements and implementation costs.

To know more:

WUR, Ghana- Rainwater harvesting for irrigation and forest landscape restoration: https://www.wur.nl/en/article/ghanas-food-basket.htm

5.1.1.4. Improved rice cultivation

Water management techniques such as alternate wetting and drying and midseason drainage limit the time rice paddies spend in an anaerobic state, thereby reducing annual methane emissions while at the same time-saving water. Additional management techniques applied to upland rice, such as fertilizer applications, residue, and tillage management practices, reduce the amounts of nitrogen and carbon emissions **(Miralles-Wilhelm, 2021)**(FAO, 2021).

Rice is a mainstay for food systems across the world. However, it also considerably impacts the broader landscapes, ecosystems, and climate in which it is grown. For instance, methane from paddy fields is equal to 10% of global methane emissions, and mismanagement of agricultural practices has led to critical mangrove and forest degradation. Since 2017, there have been efforts to build and deliver the Sustainable Rice Landscapes Initiative (SRLI) to increase resource use efficiency and reduce climate change and other environmental impacts through the sustainable transformation of rice-based landscapes.

SRLI provides a vehicle to deliver massive GHG emissions reductions through NbS while achieving a broad set of co-benefits across multiple geographies and issue areas. With a starting focus in south-east Asia, key countries include Thailand and Vietnam. Rice represents a unique opportunity for scaling up as an NbS. GHG methane emissions can be reduced by up to 70% through innovative agricultural practices, and the landscapes within which it exists are essential carbon sinks and ecosystem services, from land-based to sea-based systems. These include not just plant-based cropping systems but also livestock and forestry needs. The involvement of key food crops also means the private sector plays a vital role in delivering sustainable change along the value chain, alongside civil society, government, and research **(*Nature-based Solutions: Sustainable Rice Landscapes Initiative*, 2017)**

Credit: Photo ©

Contribution: Water management, food security, food production, and climate change.

Scale: Small scale.

Location: Thailand and Vietnam (with significant opportunity to scale up or replicate in rice-growing areas of West Africa and Latin America).

Type of NbS: Inspired.

Pros: Increased productivity, optimal resource use, reduction in GHG emissions.

Cons: Labour costs, irrigation required, and training required.

To know more:

WBCSD, Nature-based Solutions: Sustainable Rice Landscapes Initiative: https://wedocs.unep.org/bitstream/handle/20.500.11822/28814/SustRice.pdf?sequence=1&isAllowed=y

5.1.1.5. Water management on farms

Hydrologic processes are fundamental to the performance of natural systems. Therefore, good watershed management is relevant to providing NbS benefits and improving agriculture. Below there are two case studies that mix watershed management with organic agriculture and/or agroforestry. Jamaica is designing a monetary incentive program to encourage small farmers to implement solutions to increase soil and water retention on their farms. This includes the use of natural barriers, agroforestry systems, protection of forested areas, and other actions aimed at increasing and protecting soil coverage. These investments will increase farm productivity and, consequently, the well-being of the families of participating farmers. Other users in the watershed will also reap significant co-benefits, particularly the company that supplies water to households and industries in Kingston and other surrounding cities. In turn, this will boost this area’s resilience capacity in response to extreme climate events **(IICA, 2019)**. The Viva Água Movement in Brazil, led by the Boticario Group Foundation, is creating a plan to conserve and restore natural areas in Guanabara Bay’s watershed in Rio de Janeiro. They will support sustainable enterprises to restore degraded lands and transition land cultivation to agroforestry and organic agriculture in parts of the watershed that will have a positive impact on water quality **(Ozment et al., 2021)**.

Credit: Photo ©

Contribution: Water management, soil health, farm productivity, and climate change.

Scale: Large and small scale.

Location: Jamaica, Brazil.

Type of NbS: Hybrid.

Pros: Groundwater replenishment, more stable water supply.

Cons: Space requirements, costs, and not applicable in low rainfall regions.

To know more:

IICA, Nature-based solutions: Experiences and opportunities in Latin America and Caribbean agricultural landscapes. Case studies: Antigua and Barbuda, Guyana, Haiti, Jamaica, Surinam, Costa Rica, and Central America: Read more

IDB, Nature-Based Solutions in Latin America and The Caribbean: Regional Status and Priorities for Growth. Case studies related to food production: Colombia, Brazil, and Peru: https://files.wri.org/d8/s3fs-public/2021-10/nature-based-solutions-in-latin-america-and-the-caribbean-regional-status-and-priorities-for-growth_1.pdf?VersionId=.3xcu8Ruodnxf5mw9wCUAYgdEK6evOMa

5.1.2. Europe

5.1.2.1. Straw mulch and soil management

In many Mediterranean areas, citrus orchards exhibit high soil loss rates because of the expansion of drip irrigation that allows cultivation on sloping terrain and the widespread use of glyphosate. To mitigate these non-sustainable soil losses, straw mulch could be applied as an efficient solution to reduce soil losses in clementine plantations, which can be considered representative of a typical Mediterranean citrus orchard. An NbS case study in Spain showed that mulching could be used as a helpful management practice to control soil erosion rates due to the immediate effect on high soil detachment rate and runoff initiation reduction in conventional clementine orchards on sloping land, by slowing down runoff initiation and by reducing runoff generation and, especially, sediment losses. Straw mulch is also a sustainable solution in glyphosate-treated citrus plantations **(Keesstra et al., 2019)**.

Credits: Photo ©

Contribution: Soil management, food production, and runoff initiation reduction.

Scale: Small scale.

Location: Spain.

Type of NbS: Hybrid.

Pros: Retain soil moisture, prevent soil erosion, fertilization, and insulate temperature.

Cons: Insect developments and not suitable for hilly terrains.

To know more:

Straw mulch as a sustainable solution to decrease runoff and erosion in glyphosate-treated clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments: https://www.sciencedirect.com/science/article/abs/pii/S0341816218304946?via%3Dihub

5.1.2.2. Wetland restoration and Climate Smart Agriculture

In recent years, Swedish agriculture has experienced extreme wet and dry seasons. To counter the problems of drought and associated crop losses, the Tullstorpsån 2.0 project aims to store water in multifunctional wetlands when there is excess water and to 'harvest' it from storage and use it in a recirculating irrigation system. The Tullstorpsån is a 30 km long stream where landowners, organized as the Tullstorpsån Economic Association, have worked since 2009 to restore the watercourse in a holistic way to improve biodiversity and water quality (Tullstorpsån 1.0). Between 2009 and 2019, 39 wetlands covering 169 ha and 10 km of the stream were restored. Another 3-4 years of restoration work are left in this first-generation project. Having experienced severe dry and wet conditions in recent years, landowners in the Tullstorpsån 1.0 project expanded the collaboration towards climate-proofing local agriculture using NbS. This will be carried out in Tullstorpsån 2.0 from 2019 to 2025.

The Tullstorpsån 1.0 project measures include re-meandering, installing buffer strips and hedges, renaturalizing riverbed material, restoring wetlands, and adapting management. The focus of Tullstorpsån 2.0 is on a system combining multifunctional water reservoirs, recirculated irrigation, and customized drainage to adapt agricultural production to extreme weather. Two pilot schemes are underway: one is a restoration of old sugar mill ponds that are fed with water from a drainage system, stormwater, and water from the Tullstorp stream; the second is a newly constructed water reservoir fed with water from a drainage system. These systems have the opportunity to simultaneously achieve ecological, economic, and social benefits **(EEA, 2021)**.

Credits: Photo ©

Contribution: Social and environmental challenges, disaster risk reduction, climate change, food production, and water management.

Scale: Large and Small scale.

Location: Sweden.

Type of NbS: Intrinsic.

Pros: Water storage, water quality, flood risk reduction, and increasing habitats.

Cons: Larger space required and higher costs.

To know more:

EEA, Tullstorpsån 2.0 case (Sweden): adapting agriculture to wetter and drier climates: https://www.eea.europa.eu/publications/nature-based-solutions-in-europe

The Tullstorp Stream Project: https://www.tullstorpsan.se/english

5.1.2.3. Paludiculture

In the federal state of Mecklenburg-West Pomerania 291361 ha are peatlands. Currently, 57 % of the peatland area is used for agriculture (20, 531 ha as arable land, 143, 998 ha as permanent grassland) and therefore drained, causing greenhouse gas (GHG) emissions of 4.5 Mt CO2 per year. This means that drainage-based agricultural use of peatlands is the largest single source of GHG emissions in the federal state of Mecklenburg-West Pomerania. Moreover, lowering the water table leads to a significant loss of water, exacerbating climate change impacts, particularly droughts.

Climate-friendly, productive wet peatland utilization is termed 'paludiculture,' which ensures that both the land's productivity and the peat are preserved. Crops of the example region are mainly bioenergy crops and growing substrates. In other regions, options for food production are the cultivation of berries or the grazing of water buffalo. By introducing paludiculture, emission of up to 3 Mt CO2 could be avoided annually, and the role of peatlands in the water cycle and the regional climate could be partly restored. Water discharge is buffered, reducing the risks of floods and droughts, and the higher evapotranspiration has a regional cooling effect. Thus, restoring water-saturated conditions by implementing paludiculture combines climate change mitigation and adaptation benefits. Furthermore, paludiculture revitalizes the regulatory functions of natural peatlands, particularly mitigating droughts and flood events and regional climate regulation. It also enhances nutrient retention, improves water quality, and positively affects biodiversity conservation **(EEA, 2021)**.

Credits: Photo ©

Contribution: Social and environmental challenges, disaster risk reduction, climate change, food production, water management, and biodiversity.

Scale: Large and Small scale.

Location: Germany.

Type of NbS: Inspired.

Pros: Multifunctional crops (medicine, fodder, energy, food) and flood risk reduction.

Cons: High amount of water required.

To know more:

EEA, Paludiculture case (Germany): peatland restoration for climate change mitigation and adaptation: https://www.eea.europa.eu/publications/nature-based-solutions-in-europe

Greifswald Mire Centre, Paludiculture - agriculture and forestry on rewetted peatlands: https://www.moorwissen.de/en/paludikultur/paludikultur.php

5.1.2.4. Silvo-arable agroforestry

The agriculture sector in Montpellier is vulnerable to increasing temperatures and more frequent droughts. Conventional monoculture is recognized as more vulnerable than cultivating a mixture of crops or cultivating a mixture of trees and crops in agroforestry. This project addresses the impacts on agriculture of increasing temperatures or droughts, water, biotic stresses, and more extreme events by implementing agroforestry in Montpellier for over 20 years. The implementation is accompanied by research as part of the EU SAFE (Silvoarable Agroforestry for Europe) project and supported by a French national scheme to plant half a million hectares of agroforestry over 25 years, based on results obtained by INRAE at Montpellier.

Farms have adopted silvo-arable agroforestry, which combines widely spaced trees with arable crops. In practice, this has involved a combination of walnut trees and wheat. Modern silvo-arable production systems are very efficient in resource use and can capture more resources from the environment than the pure crop or pure tree systems. Trees provide shelter for crops and reduce damage due to high spring temperatures. Biodiversity is increased as it creates a diverse habitat where wildlife can live. It also helps to control pests and enhances pollination. Farmers can diversify their products, increase their income, improve soil and water quality, reduce (wind) erosion, and prevent damage due to flooding. Improving soil and water quality prevents erosion and maintains the land's productivity for future generations **(EEA, 2021)**.

Credits: Photo ©

Contribution: Disaster risk reduction, climate change, food production, land management, and biodiversity.

Scale: Small scale.

Location: France.

Type of NbS: Hybrid.

Pros: Climate Change mitigation, soil health improvement, and surplus products.

Cons: More time consumption to get benefits, occupies more land and reduces photosynthesis activity.

To know more:

EEA, Agroforestry case (France): increasing resilience and productivity: https://www.eea.europa.eu/publications/nature-based-solutions-in-europe

Climate Adapt, Agroforestry: agriculture of the future? The case of Montpellier: https://climate-adapt.eea.europa.eu/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier

5.1.2.5. Regenerative livestock

Regenerative livestock grazing is a practice that uses principles of soil health and adaptive livestock management "to improve farm profitability, human and ecosystem health, and food system resiliency" **(Spratt et al., 2021)**. Applicable in annual and perennial forage systems, such grazing mimics the behaviour and impact of wild animals: high densities of animals over short periods. Some schools of thinking consider this as a main component of regenerative agriculture.

Credits: **Photo ©**

Contribution: Environmental and societal challenges.

Scale: Large and Small scale.

Location: The Netherlands.

Type of NbS: Intrinsic.

Pros: biodiversity conservation, food production on natural lands.

Cons: risks of overgrazing when used to intensive.

To know more: Controlled grazing in natural areas https://projects2014-2020.interregeurope.eu/impact/news/news-article/5184/controlled-grazing-in-protected-areas/

5.1.3. The Netherlands

5.1.3.1. Landscapes and food systems

People often use the concept of the landscape when they speak of a certain aesthetic appearance of particular surroundings. Usually, the concept refers to some ideal or nostalgic reference. For example, most Western European people envision a pastoral picture in their mind when thinking of a countryside landscape, without many houses and probably with small herds of cattle roaming around. From a natural viewpoint, this archetypical vision of a countryside landscape connects to arcadian nature **(Schouten, 2018)**, which is nature that thrives next to small-scale, extensive agriculture. Within the context of the Netherlands, the concept of landscape has helped to overcome the perceived division of nature and culture by integrating natural elements as part of its cultural experience. Therefore, certain NbS can become part of Dutch heritage, and people take ownership over them. Examples derived from small-scale initiatives like the recognition and reintroduction of wooded banks on farmlands which can reinforce ecological resilience by building toward silvopastoral systems **(Luske, 2015)**, to the recognition and protection of the Dutch Wadden Sea as a UNESCO world heritage; safeguarding both its ecological characteristics and the Dutch internalization of the Wadden Sea as maritime-agricultural landscape **(Egberts, 2018)**. This enables creativity in combining the natural state of affairs with valuable contributions to society. For example, Royal Haskoning DHV is working on dike-reinforcement strategies (hybrid NbS), which do not just keep water out but also align with the natural transition between land and sea, creating habitat for local marine biodiversity. From a food system perspective, some innovative initiatives are unfolding on the Dutch Wadden Islands. Waddenwier and The Salt Farm Foundation, both based on Texel, are two promising initiatives in the development of aquaculture and saline agriculture.

Credits: **Photo ©**

Contribution: socio-cultural challenges, food production.

Scale: Large scale.

Location: The Netherlands.

Type of NbS: Hybrid.

Pros: Achieve multiple goals (i.e., food and fodder production and flood reduction)

Cons: Complex processes and multiple stakeholders involved.

To know more:

Royal Haskoning DHV, Nature-based solutions for Lauwersmeer dike reinforcement: https://global.royalhaskoningdhv.com/projects/nature-based-solutions-for-lauwersmeer-dike-reinforcement
Waddenwier, Innovative organic seaweed farm on Texel: https://waddenwier.com/en
Salt Farm Foundation, Promoting Saline Agriculture: https://saltfarmfoundation.com/

5.1.3.2. Flower edges around crop fields

Nature-inclusive agriculture is a term used under the NbS umbrella to create more resilient ecosystems. Flower- and herb-rich grasslands help to increase biodiversity and are a way to produce food within the boundaries of nature. Temporary flower edges around crop plots, and fallow land was sown in with flowering plants and are already applied in multiple places in the Netherlands to stimulate functional biodiversity for natural pest control and pollination. In several provinces, subsidies are available for farmers to create flower edges, like in Flevoland and the southwestern part of the country. In Noord-Holland, experiments are done in pilots with flower edges on fields where onions are cultivated. Using domestic plants also contributes to biodiversity conservation and provides specific habitats for specific domestic bees or other insects, working as well as pest control **(Erisman et al., 2017)**.

Credits: **Photo ©**

Contribution: Biodiversity challenges and natural pest control in arable farming.

Scale: Small scale.

Location: The Netherlands.

Type of NbS: Hybrid.

Pros: Reduction of pesticides use and biodiversity.

Cons: Extra costs, space, and specialist requirements.

To know more:

WUR, Nature-inclusive agriculture (in Dutch): https://v3.jamdots.nl/view/30079/Natuur-Inclusieve-Landbouw

5.1.3.3. Agroforestry and woody vegetation

The term agroforestry is used for a cultivation system in which trees or shrubs are combined with annual crops, grassland, and livestock. An example of agroforestry is the combination of fruit or nut trees with arable crops, but many other combinations are conceivable. Agroforestry offers great opportunities for developing more resilient, efficient, and robust food production systems with benefits for farmers, the environment, society, and the ecosystem **(Schoutsen et al., 2020)**. In the Netherlands, some examples are woody plants along ditches to keep pesticides away from the ditch water. It is practised in fruit plantations to ease the use of pesticides and reduce the required safety distance from ditches. Well and adequately managed woody strips could equally reduce the disease and pest pressure on the fruit trees due to the potential provision of habitat for pest predators. Other examples are the wooded banks (in Dutch "houtwal") and bocage ("coulissenlandschap"). They are used as a windbreak, demarcation of property, natural fence, to cut firewood, as a habitat and biodiversity reserve, as a corridor to connect different habitats, and potentially to harvest fruits and nuts. Hedgerows on mounds ("graften") in hilly areas can help to reduce water runoff and erosion and, by doing so, retain fertile soil and water **(Natuurmonumenten, 2022)**. This helps maintain food production and cope with more extreme weather events (climate adaptation) and CO2 storage (climate mitigation).

Credits: **Photo ©**

Contribution: Environmental, biodiversity, and climate change challenges, and resilient food production.

Scale: Large and small scale.

Location: The Netherlands.

Type of NbS: Hybrid.

Pros: Reduce erosion, provide habitat for biodiversity, and timber production

Cons: Space requirements and restorations take a long time.

To know more:

Natuurerf, Wooded banks-Houtwal (in Dutch): https://www.hofvogels.nl/natuurerf/natuurerf-houtwallen/

5.1.3.4. Strip cropping

Strip cropping can create a robust, plant-based food production system. Strip cropping can help to reduce the geographical spreading of pests and diseases within fields by a high spatial variety of crops. Furthermore, it provides shelter and habitat for local species and biodiversity. In this way, food production can be realized with less chemical pesticides while using structures adapted to agricultural machinery. Strip cropping is being done on the operational scale by ERF BV near Almere **(ERF BV, 2021)**, and WUR executes experiments at the Farm of the Future in Lelystad **("Farm of the Future in Lelystad," 2022)**. The tested rotation is based on the crops most commonly grown by arable farmers in the Netherlands and on local practice. The rotation consists of grass-clover, cabbage, onion, potato, wheat, and carrots **(Ditzler et al., 2021)**.

Credits: **Photo ©**

Contribution: Environmental, biodiversity, and climate change challenges, and reduction of chemical pesticides on arable farms.

Scale: Large and small scale.

Location: The Netherlands.

Type of NbS: Inspired.

Pros: Spatial diversification and natural pest control.

Cons: Adapted machinery required and complex management.

To know more:

WUR, Strip cropping: https://www.wur.nl/en/project/strip-cropping.htm

5.2. Reflections on nature-based solutions at different scales

As seen in the examples above, NbS can be implemented at different geographical scales, in different habitats and can contribute to different global challenges. Most examples of NbS in food systems show that NbS were implemented at a large- and/or small-scale level (landscape or farm-level). In terms of socio-economic and cultural challenges, there is a risk of suggesting "solutions" without defining clearly the problem, who created such problems, or what types of risks (e.g., corporate greenwashing, disservices and maladaptation) are involved. In the NbS planning process, environmental and societal opportunities, as well as challenges, must be well appreciated and defined. This way, the correct scale, habitat and NbS intervention type (intrinsic, hybrid, inspired) can be identified and implemented. As learnt from the examples in Europe, the Netherlands and from the global south, NbS make use of and support natural processes such as physical, chemical and biological, which are relevant for the continuation of ecosystem services and sustainable food production.

The NbS of the different case studies show their contributions to the environment (e.g., water management to improve water quantity and quality), climate change (e.g., carbon sequestration or climate adaptation for disaster risk reduction), biodiversity (e.g., improving habitats and support of local species), and socio-economic and cultural contributions (e.g., human health and wellbeing or improving agricultural output and income), depending on the spatial scale applied.

Not all the case studies considered the different stakeholders and beneficiaries involved. The effectiveness of NbS is related to the scale of implementation (e.g., country, regional, landscape, farm level) and foremost to the acceptance and ownership of multiple stakeholders. Some examples we provided are effective on small scales and do not need the involvement of many stakeholder groups, like the flower edges or strip cultivation. However, other examples require a larger scale of implementation, like watershed management. This also means that more stakeholders need to be involved and must be willing to shape the NbS.

Likewise, it was noticed that next to the spatial scale, the temporal scale is not considered. Temporal scales for NbS implementation might have an important impact on calculating the cost-benefit of different measures and even support the planning of NbS business models. Geographic, spatial and temporal scales are relevant to identifying the types of policies, legal, governance and financial mechanisms that can support NbS implementation for sustainable food production.

Finally, not much was found on the scaling dimensions of the NbS case studies, like their potential to scale up (replication on similar contexts), scale out (scaling in a different context), and scale deep (transforming the system). Just a few examples mentioned their local context and the types of barriers they were facing.

6. Supporting multi-stakeholders, tools and business models to jointly explore potentials for nature-based solutions

Over the last ten years, UN institutions (UN Environment, UN Development Programme, and Food and Agriculture Organization), as well as international conservation organizations (e.g., International Union for Conservation of Nature (IUCN), World Wildlife Fund (WWF), BirdLife International and Conservation International), have been implementing community-led nature-based approaches for climate adaptation (i.e., ecosystem-based adaptation) and/or ecosystem-based disaster risk reduction projects across the globe (Rizvi, 2014). At the United Nations Food System Summit 2021, promoting nature-positive production was cited as a potential enabler for systemic solutions (UNFSS 2021), as one of its main purposes is to manage existing food production systems sustainably, to the benefit of both nature and people.

According to Nesshöver et al. (Nesshöver et al. 2017), the European Commission uses the concept of NbS to foster transdisciplinary research for solutions based primarily on nature, rather than using costly materials and energy, and this help to overcome sustainability issues, which otherwise accrue from development approaches that are too narrowly and exclusively focusing on economic benefits at the short term. The authors praise the integrative character of NbS, which requires a broad range of stakeholders with different types of experience and expertise who work together and, by this, try to assure that all dimensions of sustainability are being addressed. Nevertheless, the authors are aware that such solutions also come or may come with a substantial price attached to them.

As a tendency, the term and concept NbS in a rural context is more used for processes at a landscape scale than very limited in space. This automatically calls for concerted action by stakeholders from different sectors, along with consistent policies. This may sound evident, though it offers a broad range of potential questions and controversies in implementation. Stakeholders may perceive problems differently from which solutions are searched for. What is considered eligible as NbS can be questioned. At best, a flow of benefits accrues from NbS, though there can also be trade-offs, disservices and disbenefits for specific people. Moreover, effects are not always sufficiently predictable. Adaptive management appears to be best suited to address such uncertainties and complexity in implementing NbS (Nesshöver et al., 2017). A collaborative learning process, including adequate documentation of failures, is then a must.

Evaluation of the effectiveness of NbS is especially tricky when looking at the landscape scale and considering the multiple objectives that are aimed. While the carrying out of specific management actions can be assessed relatively easily, their outcomes are less easily tracked and may accrue on different spatial and temporal scales. Nesshöver et al. (Nesshöver et al., 2017) conclude that participatory, descriptive approaches might be the most useful here as they also provide sufficient (local) context information relevant for policy makers.

How much natural inspiration is beneficial to agriculture is a point brought up by scientists challenging the recent discourse on NbS in food and farming systems ((Sumberg, 2022), editorial). People doubt that nature is always an advantageous source of inspiration for agriculture, respectively. They challenge the assumed statement that the more natural, the better for society and that nature might be anyhow "right". This attitude could be partly reinforced using a specific type of language that differs from common scientific language.

Agriculture with NbS represents a broad spectrum and is not necessarily pretending to be nature. It is rather fostering environmental or natural mechanisms, context-bound, in agricultural systems which are designed to deliver more streams of benefits than financial returns only. A critical attitude towards actions and the observation of results is essential to this system. Scientific analysis currently lags ongoing learning by doing by farmers, which is partly supported by "non-scientific" players such as civil society, companies and foundations. Science can catch up when it comes to taking challenging ideas seriously and working together to decipher the pros and cons. This transdisciplinary cooperation to further our understanding of NbS necessarily involves a joint revision of evaluation frameworks and objectives (Sumberg, 2022).

NbS are hard to scale in society as long as the productivist paradigm of agriculture prevails, where financial profit in the short-term counts that does not need to compensate for related negative environmental and social impacts. As an example, van der Werf and Bianchi (Van Der Werf and Bianchi, 2022) conclude in their review that nature-based pest management comes with benefits and costs. According to the authors, society must be willing to compensate farmers for potential revenue foregone when not applying pesticides, which are generally more reliable in controlling pests and safeguarding harvests. There are generally two ways to steer: encouraging environmental stewardship through economic instruments or mechanisms and discouraging management that does not account for negative impacts accruing from pesticide production up to its application.

Thus, scaling NbS requires efforts in the broader economic system, calling for cooperation across sectors and agricultural producers, as well as the rethinking of the productivist paradigm. This is in line with efforts to pay for ecosystem services, such as carbon farming and penalizing production for its GHG emissions. Similarly, prices of products need scrutiny and action involving trade and consumers. NbS questions that agriculture is a sector that should be limited to food (and fiber, etc.) production only. The explicit aim of NbS to contribute equally to societal well-being offers opportunities to organize and value agriculture's role in society as cross-sectoral. Public health, environment and labor are examples (Van Der Werf and Bianchi, 2022).

According to FAO (FAO, 2021b), transitioning to nature-based agricultural practices can yield significant direct and indirect benefits to society and to farmers. However, for many agricultural producers, this transition involves a fundamental change in the ways in which they use their scarce land, aquatic resources (including freshwater and fish resources), labor and capital. The direct and opportunity costs of these changes are immediate and non-trivial, while the benefits can take years to manifest. This is because the biological processes and knowledge required to restore agricultural ecosystems and leverage natural processes to replace synthetic agricultural inputs take time. In some cases, the period of transition can even result in a short-term reduction in crop, livestock or fish yields and an increase in yield variability.

In order to achieve the desired scale and pace of NbS adoption by stakeholders and agricultural producers, programs must be designed with recognition of traditional farm practices and to rebalance the incentives for individual farmers. Critical considerations in successfully planning and implementing NbS in the agri-food sector include (FAO, 2021b):

- **Planning Scale and Time Horizons:** Consider measures and benefits at a regional or watershed scale and examine longer time horizons in order to fully capture the long-term benefits.
- **Synergy and Trade-offs:** Examine the synergies of multiple NbS practices, the opportunity to pair green and grey projects, and the potential trade-offs of various practices.
- **Technical Assistance:** Provide technical assistance to raise awareness and increase the likelihood of successful implementation of new practices.
- **Policy and Regulation:** Create policy incentives or regulatory frameworks that can enhance the adoption of new NbS practices and deliver additional public benefits and lead to economic externalities being captured in the pricing of goods and services.
- **Business Models:** Enable financial models and new corporate practices that will level the playing field for NbS and enhance investment in these new practices over time.

6.1. Nature-based solutions tools

A large variety of tools and data have been developed worldwide to support the mainstreaming and uptake of NbS, ranging from methodologies, software, catalogues, repositories and e-platforms to guidelines and handbooks. NbS tools and data can make a valuable contribution to overcoming the barriers that hamper the wide uptake and implementation of NbS. Tools can, for example, inform and aid the planning processes by selecting and evaluating NBS, simulating NbS implementation, calculating the costs and benefits of NbS, supporting stakeholder involvement and facilitating collaborative processes. End-users can only benefit from these tools and data when they are aware of their existence, and they can compare the diverse available tools and they can make an informed selection of the instruments suitable to address specific challenges and adapt them to their specific needs and local contexts (Voskamp et al., 2021).

In Box 3, there are several tools collected that can provide relevant data to policymakers, government officers, food companies, agricultural producers and other actors from the agri-food sector:

Box 3. Examples of NbS tools for the agri-food sector

PANORAMA Tool: This is an online catalogue and repository tool available in English, French and Spanish languages. The examples offered in this tool help to plan, design, and analyse NbS. Likewise, it offers examples that can inform and inspire end-users. It provides types of ecosystems (agriculture, desert, forest, marine and coastal, freshwater, grassland and urban ecosystems).

As well it offers information about biodiversity, climate change, ecosystem conservation, financing, gender mainstreaming, governance, human development, infrastructure, islands, local communities, management planning, outreach & communications, science and research, sectors, standards/certification, waste and resource efficiency and world heritage.

The PANORAMA tool offers solutions for a healthy planet and is a partnership initiative to document and promote examples of inspiring, replicable solutions across a range of conservation and sustainable development topics, enabling cross-sectoral learning and inspiration. PANORAMA allows practitioners to share and reflect on their experiences, increase recognition for successful work, and learn with their peers how similar challenges have been addressed around the globe.

Link: https://panorama.solutions/en

OPPLA E-platform Tool: is the EU Repository of Nature-Based Solutions. It provides a knowledge marketplace where the latest thinking on natural capital, ecosystem services and nature-based solutions is brought together. Its purpose is to simplify how the community shares, obtains and creates knowledge to better manage our environment.

Oppla is an open platform that is designed for people with diverse needs and interests from science, policy and practice; public, private and voluntary sectors; organizations large and small, as well as individuals. In the Oppla Marketplace, end-users can obtain guidance, software, data and other useful resources, as well as promote the outputs of projects or networks.

Pros: Overview of knowledge

Cons: focus on Europe

Link: https://oppla.eu/

RECONECT: RECONECT demonstrates, references and upscales Nature-Based Solutions in rural and natural areas. It forms the basis for the proof-of-concept regarding large-scale NbS demonstrations by co-creating new cases and connecting to existing cases and sharing experiences with European and International collaborators (Network of cases). Focuses on 'land use planning', specifically on river basins.

RECONECT promotes and pursues innovation in relation to the evaluation, selection, design, operation, maintenance and decommissioning of Nature-Based Solutions. The ICT tool provides real-time information about the performance of NBS and the evidence base to facilitate co-creation and enable replication and upscaling.

Link: http://www.reconect.eu/

MEDACC: Adapting the Mediterranean to Climate Change Tool: This informative and inspirational tool aims at testing innovative solutions in order to adapt agro-forest and urban systems to climate change in the Mediterranean basin. Thus, MEDACC contributes to the design and implementation of adaptive strategies and policies which are being developed at the national and regional levels in the Euro-Mediterranean area.

The MEDACC project developed pilot actions to test adaptation measures in the agriculture, forestry and water management sectors. It informs about the involvement of local stakeholders and the assessment of the main impacts of climate change and territorial vulnerabilities on the watersheds.

Link: http://www.medacc-life.eu/medacc-adapting-mediterranean-climate-change

Nature-based Solutions Evidence Platform: The tool aims to consolidate the largely dispersed evidence-base on the effectiveness of NbS for addressing climate change impacts and to make it available as an open-source, dynamic and updatable user-friendly online platform. It offers country and regional information. The tool explores the evidence on how effective different nature-based interventions are for addressing climate change impacts, compares social, economic, and environmental effects of different nature-based interventions, filters by region, country, biome, or type of outcome, generates maps, graphs and download data, and links the evidence to Nationally Determined Contributions. **Link:** https://www.naturebasedsolutionsevidence.info/evidence-tool/
Water Climate Toolbox: The Toolbox presents several tools and techniques to support adaptation action. From each tool or technique, the definition and objective are described, as well as the issues to consider, advantages and challenges. The scope of the toolbox is limited to the water sector. The Water-Climate-Toolbox is aimed at water sector practitioners and offers the following tools and techniques to support adaptation action: Climate Change Adaptation, Climate Monitoring and Prediction, Dams and Reservoirs, People-Centred Early Warning Systems, Economic Incentives for Ecosystem Protection, Flood Sensitive Planning, Improved Stormwater Drainage, Irrigation Technology and Methods, Rainwater Harvesting, River Basin Management, Sustainable Groundwater Management, Virtual Water, Water Loss Reduction, Water Pricing, Water Reuse, Water Stewardship, Waterless Systems, Artificial Recharge, Desalination, Ecological Restoration, Preservation of Ecosystem Functions, Vulnerability Assessment, Climate Education. **Link:** https://wocatpedia.net/images/c/c7/Waterclimatetoolbox.pdf
Catalogue of bio-based solutions: The information in the catalogue aims to provide inspiration and orientation for stakeholders, whether policy makers, industry or other parties interested in bioeconomy. This online database contains fact sheets on existing biobased solutions with vetted potential for market uptake in bioenergy, biomaterials, biochemicals, and food and feed. **Link:** https://www.bio-based-solutions.eu/#/
Global Database on Sustainable Land Management – WOCAT: The sustainable land management (SLM) database of technologies and approaches. The term NbS is hardly used here. Though, most practices described here by practitioners are indeed using nature or natural mechanisms to solve local problems related to agriculture and the natural resources available. This global database has been recommended by the UNCCD; WOCAT and UNCCD have signed a partnership. The network was founded in 1992 in Switzerland. From 2022 onwards, WOCAT will be hosted by ISRIC (Wageningen). **Link:** https://www.wocat.net/en/global-slm-database/
IUCN Global Standard for NbS: IUCN has developed the first-ever Global Standard for Nature-based Solutions to help users design, implement and verify NbS actions. Governments, companies, NGOs and others can use the IUCN Global Standard, user guide and self-assessment tool to consistently design effective NbS projects that are ambitious in scale and sustainability, creating a shared language and framework for stakeholders and innovative partnerships. Donors and financers can invest in NbS with confidence that the Standard provides a benchmark, minimising risks and adding assurance. All user groups across the public and private sectors can also further engage with the governance structure of the Standard, which connects stakeholders worldwide and ensures that the Standard is being used to its full potential to mainstream NbS around the world. **Link:** https://www.iucn.org/theme/nature-based-solutions/resources/iucn-global-standard-nbs
Foodbank community platform: It is a global community e-platform for farmers and producers, policy makers and government leaders, researchers and scientists, academics and journalists, and the funding and donor communities to collaborate on providing sustainable solutions for our most pressing environmental and social problems. Foodbank aims to educate, inspire, advocate, and create change in the agri-food sector. They support environmentally, socially, and economically sustainable ways of alleviating hunger,

obesity, and poverty and create networks of people, organizations, and content to push for food system change. **Link:** https://foodtank.com/
Nature-based Solutions Investment Platform: The platform is designed to enable allocators to see the landscape of climate opportunity in one place, to inform strategy, navigate, source and execute investments aligned with science-based net zero pathways. **Link:** https://nbs.capitalforclimate.com/about
Nature-based Solutions Database: It is an interactive map to search tools and case studies worldwide - on five continents, 500+ communities and thousands of ideas-. The NbS Database helps to learn how outstanding local communities and indigenous peoples around the world are making possible the achievement of the UN Sustainable Development Goals through nature-based actions. **Link:** https://www.equatorinitiative.org/knowledge-center/nature-based-solutions-database/

6.2. Business models for implementation and upscaling of nature-based solutions

Research developed by Mayor et al. (Mayor et al. 2021) mentions that realizing funding for NBS remains a challenge. When the concept of NbS for societal challenges was first defined by the European Commission in 2017, financing was recognized as one of the major challenges to its mainstreaming. The complexity of NbS finance has its origin in the multiple benefits/stakeholders involved, which obscures the argument for both public and private sector investment. Since 2017, subsequent waves of EU research- and innovation-funded projects have substantially contributed to the knowledge base of funding and business models for NbS.

Pressure on public finances is not the only reason innovation in financing and business models for NbS are required. Open innovation/transition approaches to dealing with societal challenges recognize the benefits of engaging citizens and societal actors in creating solutions that respond to the specific challenges of their local environment and in designing solutions to meet these needs. The role of government in this approach includes the articulation of user needs, co-creation of a common vision, coordination of policies and tentative governance ("Innovation in financing and business models for NBS. Why?" 2020). The Nature-Based Solutions Business Model Canvas developed by the Connecting Nature project ("Innovation in financing and business models for NBS. Why?," 2020) helps to address the six major challenges to innovation in NbS financing and business models by:

- Reversing the focus on financing capital investment to start with business model planning for long-term sustainability.
- Broadening the value proposition to include a focus on environmental, social and economic benefits, the identification of new stakeholders and alternative ways of capturing value. This approach, in turn, may lead to the identification of new sources of financing.
- Bridging 'silo' gaps – both internally within public sector organizations and externally with different stakeholders. This helps to build a common vision & broader understanding of NbS potential for all stakeholders.

- The NbS Business Model Canvas facilitates capacity building and is supported by a comprehensive guidebook with multiple case studies.
- Trade-offs between economic and other considerations are explored during the first step in the process of establishing the different value propositions.
- The NbS Business Model Canvas enables the clear identification of key stakeholders to be involved and consideration of how they can be engaged through different governance models.

Business Models help to describe the rationale of how an organization creates, delivers, and captures value in economic, social, cultural or other contexts (Beatriz Mayor, 2019). Business model canvases are commonly used as a starting point for the design and planning of more detailed business models for NbS. These canvases help identify the required components of a business model and organize the information with the goal of communicating to investors, promoters, and the public. Some of the NBS-adapted canvases produced within the H2020 framework are the Connecting Nature NbS business model canvas, the NAIAD NAS canvas, the EdiCitNet canvas for ECS, and the Think Nature canvas (Mayor et al., 2021).

NbS are a relatively new concept and sometimes difficult to explain to people who are unfamiliar with the concept. The Nature-Based Solutions Business Model Canvas provides a simple way of telling others what it is intended to do and why, who needs to be involved, and how to make it happen. The Nature-Based Solutions Business Model Canvas uses language which is widely understood by people from many different backgrounds and is a useful first step for individuals or groups to use to plan the implementation of a project. By considering the value that NbS may offer to different groups of people, the Nature-Based Solutions Business Model Canvas helps to identify potential new partners or beneficiaries that may be interested in getting involved in the planning, implementation or ongoing maintenance of Nature-Based Solutions. Combining reflections on the value of NbS with the identification of new partners may help to identify potential sources of initial NbS financing or partners who could help with financing ongoing costs or contributing to cost reduction (Siobhán McQuaid, 2019).

The Horizon 2020 project NAIAD (Nature Insurance Value: Assessment and Demonstration) collected good international practices in financing and funding nature restoration. Their research presents a compilation of successful initiatives to fund and finance nature restoration projects, including but not limited to risk reduction projects. The collection is divided into two sections that offer analyses through two different lenses. The first section analyses a set of successful examples of NbS projects through a business model lens by applying the natural assurance scheme (NAS) canvas framework. This NAS framework is a linearized sequence of clusters and steps to intuitively identify and describe all the components of a business model, following a market logic for service provision: from supply through to demand and leading to impact. The second section reports on a set of successful examples of funding and financing mechanisms for ecosystem restoration initiatives, including facilities and instruments. This collection thus provides an overview of the evidence of existing successful examples of business models, instruments, and facilities for the funding, financing, and implementation of NbS projects (see Figure 5) (Mayor et al., 2021).

<table>
<tr><th>Cluster C. SUPPLY</th><th colspan="2">Cluster A. FLOW OF ES SERVICES</th><th colspan="3">Cluster E. DEMAND</th></tr>
<tr><td>STEP 4. WHO IMPLEMENTS
(who takes the responsibility)</td><td colspan="2">STEP 1. PROBLEM TO BE ADDRESSED</td><td colspan="3">STEP 9.WHO OWNS THE PROBLEM
(who is affected)</td></tr>
<tr><td>STEP 5. Key activities
(Measures composing the strategy to address the problem)</td><td colspan="2">STEP 2. VALUE PROPOSITION
(Main service provided)
(Damage costs/avoided costs + value of co-benefits)</td><td colspan="3">STEP 10. CUSTOMER SEGMENTS</td></tr>
<tr><td>STEP 6. Key resources
needed to implement measure e.g. knowledge, people and capacity, legal frame, political support, other, ….</td><td>2A. Primary service and value (Main service and risk function-risk reduction and prevention)</td><td>2B. Secondary service and value (co-benefits and associated values)</td><td>10A. Direct Beneficiaries
of primary value (damage costs/avoided damages)</td><td>10B. Clients
the ones who pay for the service</td><td>10C. Extended Beneficiaries
(real and potential) of main value and co-benefits</td></tr>
<tr><td rowspan="2">STEP 7. Key Partners
key stakeholders you need to engage with to obtain the resources</td><td colspan="2">Cluster B. Regulatory context
STEP 3. Regulation</td><td colspan="3">Cluster F. REVENUE STREAMS
Step 11. Revenue stream:
(Income streams associated with services/value generated, including private sector and private investments)</td></tr>
<tr><td colspan="2" rowspan="2">Cluster E. Supply-demand interactions
STEP 13. CUSTOMER RELATIONSHIPS
(type of communication between service provider and clients)</td><td colspan="3" rowspan="3">Step 12. Funding coming from
12A. Tariffs
12B. Taxes
12C. Transfers
12D. Private</td></tr>
<tr><td>Cluster D. COST STRUCTURE
STEP 8A. Life Cycle Costs
Costs of implementing the NBS measure
Including capital, operation and maintenance</td></tr>
<tr><td>STEP 8B. Opportunity costs
Avoided benefits from implementation of alternatives.</td><td colspan="2">STEP 14. CHANNELS
(means of communication between service provider and clients)</td></tr>
<tr><td colspan="6">CLUSTER H. IMPACT
STEP 15. IMPACT THROUGH KPIS</td></tr>
</table>

Source: **Red:** NAIAD; **Blue:** NAIAD deliverables; **Green:** Business Canvas; **Purple:** Inclusive business canvas

Figure 1. NAS canvas

FIGURE 5: BUSINESS MODEL CANVAS WAS DEVELOPED BY THE NAIAD-H2020 PROJECT (SOURCE: BEATRIZ MAYOR, 2019).

The Connecting Nature (2019) developed another NbS business model canvas, which was adapted from the original Business Model Canvas developed by Osterwalder and Pigneur that consisted of 3 major elements:

- **Value proposition:** what the customer or end-user wants?
- **Value creation and delivery:** who is needed to create and deliver the value proposition?
- **Value capture:** How much will it cost to deliver the value proposition, and how to pay for the product or service delivered?

The Nature-Based Business Model Canvas is based on these three key building blocks but begins with an expansion of the value proposition to consider not just the benefits for individuals but the broader environmental, economic and social value proposition (see Figure 6) (Siobhán McQuaid, 2019).

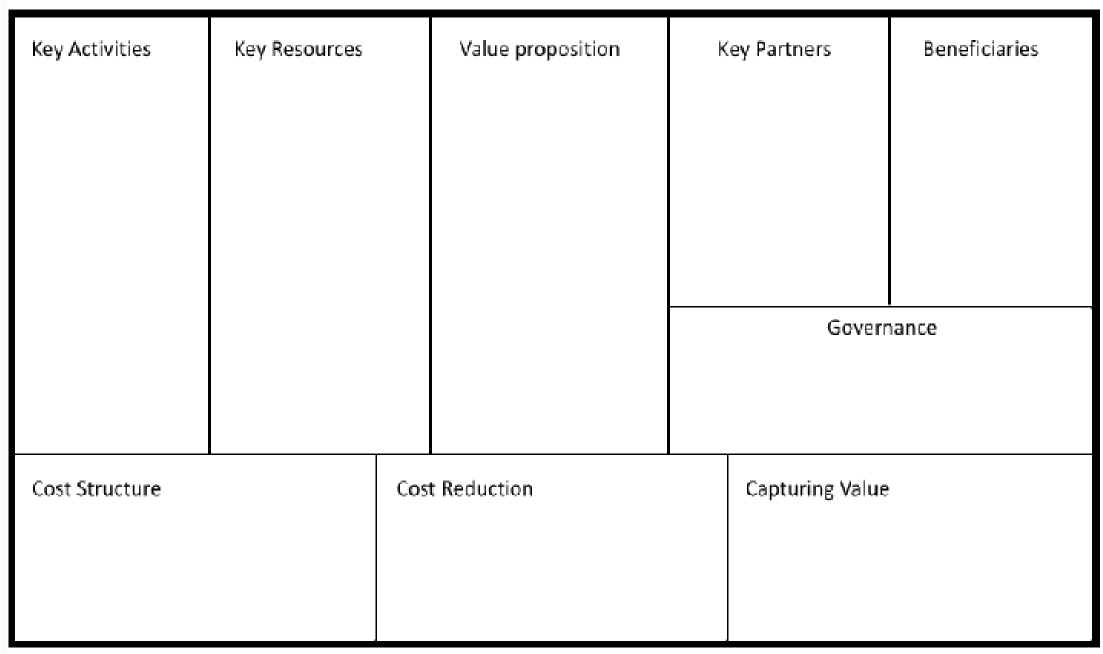

FIGURE 6: BUSINESS MODEL CANVAS WAS DEVELOPED BY THE NAIAD-H2020 PROJECT (SOURCE: BEATRIZ MAYOR, 2019).

The engagement of different actors, mainly agricultural producers, to an enabling environment should happen in the early stages of the NbS implementation and aligned to the local context within which the project will be operating, and this can make influence the success or failure of the business model. While farmer uptake of promising NbS is at the core of the model, success often requires an ecosystem of actors such as non-governmental organizations (NGOs), policymakers, corporations and others, loosely coordinating their efforts and thoughtful policy and institutional engagement in order to achieve desired environmental and social impacts at scale (FAO, 2021c).

While developing the business model canvas, it is important to consider several types of financing mechanisms and incentives that can increase the adoption of NbS in agriculture. For instance, lending and investment instruments can include debt (commercial loans or bonds), equity (private equity funds or publicly traded companies), insurance risk management, payments for services, and public policies (like tax incentives, carbon pricing, or water tariffs). In many cases, private and public finance can work together (e.g., blended finance) to enable investment. For example, there may be cases where risk is too high for private investment alone, or the public finance available is insufficient, thus creating a need to blend finance types. The structure of financing (and governance) for agriculture NbS can present opportunities and challenges. Unfortunately, structures and processes of creating shared incentives for undertaking the financial burden of natural infrastructure projects are not well understood yet (FAO, 2021c).

6.3. Reflections on supporting stakeholders, tools and business model canvas for nature-based solutions implementation

NbS projects in the agri-food sector need to consider the different stakeholders and actors involved before, during and after their implementation. Likewise, it is necessary to consider the complex biophysical and political context, the culture and socio-economic factors of the agricultural producers and organizations involved, which vary widely by individuals, gender, type of landowners, and business size.

Climate adaptation and mitigation challenges are also to be considered, along with the specific constraints that different farmers, agricultural producers and other actors face, including access to natural resources, credit, markets, and infrastructure. Some relevant barriers to the adoption of NbS mentioned by FAO (FAO, 2021c, 2021b) to be considered in Europe and in the global south can include the decentralized business operations, the internal resistance to change of agricultural producers and governments, lack of in-house expertise to handle site-specific issues with NbS deployment, regulatory risk, company brand concerns, lack of internal resources dedicated to these technologies, and perceived uncertainty in terms of costs and performance of NbS.

The list collected of NbS tools for the agri-food sector is not a complete overview of existing tools. Potentially valuable tools can be missing or underrepresented as a result of the quick search and selection criteria during this research. Therefore, to learn more about the different NbS tools to support the agri-food sector, further research is recommended. There is not just one intended user (group) nor one specific part of the NbS uptake process that should be supported by tools. Rather, there are different potential end-users such as food organizations, farmers and other agricultural producers, government officers, scientists, practitioners, and community organizations, among others that could make use of such tools.

The NbS tools can aid in the planning, design, implementation, monitoring and evaluation phases as well as help to address specific challenges end-users are facing. Some tools could be easy to understand and use, while others might need an in-depth understanding and/or training on how to apply the tool. The language in which a tool is provided can be a barrier or an enabler to using certain NbS tools. If tools are in English, potentially, a higher number of end-users can make use of the tools. On the other hand, if a tool is not provided in the native language, some end-users are likely to face a language barrier.

The NbS Business Model Canvas can help to identify significant economic and societal benefits for agri-food actors, businesses and governments. When evaluating the suitability of NbS projects, it is important to understand the business model case for that investment from the perspective of multiple stakeholders and beneficiaries. Investments in NbS projects for the agri-food sector are increasing as they create a positive return for society and the environment. NbS investments are currently (politically) motivated by public institutions and private organizational commitments to sustainability with the aim to contribute to a greater global agenda.

7. Conclusions and Recommendations

NbS is a rather new (umbrella) concept, and several definitions exist. Every definition, however, aims at using natural processes to address societal and environmental challenges, like climate change adaptation, food production and biodiversity loss. Many terms related to sustainable agriculture and food production fit under the umbrella of the NbS concept. The preference for one definition over another is often related to the purpose and context of the user.

Three different types of NbS can be distinguished: Intrinsic (make better use of existing nature), hybrid (modifying managed ecosystems) and inspired (design and management of new ecosystems). Since the NbS concept is so broad, the risk exists that it becomes too vague or confusing for proper application. On the contrary, thinking and working with nature instead of fighting natural processes is promising but requires a change in mindset. One that NbS can help to achieve.

Nature and ecosystem dynamics are undoubtedly an inspiration to move from linear food production systems to circular food production systems when possible. The main purpose of circularity is to optimize resource consumption and minimize emissions to avoid resource depletion, climate change and degradation by closing the loop of materials and substances. NbS provide arrangements of multi-functional services. This implies recovery, retention, and production of nutrients and/or minimization, degradation, and valorization of residual streams, which agrees with the circularity concept. Ideally, NbS work in a very efficient way (from an energetic and material point of view) and additionally adapt to local conditions. Nevertheless, we need to be aware that the viable implementation of nature-based and circular solutions in our society and current economic system requires interdisciplinary integrated solutions towards food security, financial and legal modifications, and climate change considerations.

Some NBS drivers identified were climate risks, a shift in the societal valuation of ecologically sound practices, and a pragmatic approach to problem-solving where NbS can be cost-effective. Currently, NbS has received a lot of attention in political discussions of several international organizations. This provides opportunities for further upscaling of NbS to address challenges in food systems.

Nevertheless, several barriers arise in the current food systems that hamper the uptake of NBS in agriculture worldwide. Five important categories of barriers were identified: 1) Financial barriers prohibit uptake of NBS; 2) Perspective and opportunities for farmers towards a transformed food system with NbS are lacking; 3) A lack of vision in governments and a lack of shared vision with other stakeholders hinder effective governance towards NbS uptake; 4) Knowledge-related issues related to the education of future farmers and advisors, lack of knowledge sharing from current applications of NbS and regime actors pushing conventional farming practices in agricultural education. Recognition and utilization of local knowledge are lacking; 5) Overarching these problems is resistance from the current dominant regime and problematic power relations between actors in the food system.

The different NbS case studies in the Netherlands, Europe and global south, mentioned directly or indirectly their contributions to the environment, climate change, biodiversity, and socio-economic and cultural contributions. Temporal scales for NbS implementation have an important impact on calculating the cost-benefit of different measures and even support the planning of NbS business models. Geographic, spatial and temporal scales are relevant to identifying the types of policies, legal, governance and financial mechanisms that can support NbS implementation for sustainable food production. The effectiveness of NbS is related to the scale of implementation and foremost to the acceptance and ownership of multiple stakeholders.

The involvement of stakeholders is key for successful NbS design and implementation. Different stakeholders have different views on problems, and thus in the need to select different solutions. We found out that the benefits of NbS are not always clear or not clearly distributed among stakeholders. Applying participatory approaches can help to increase acceptance. The current productivist paradigm clashes with the long-term multi-benefits (including non-financial benefits) that NbS can deliver. Critical considerations in successfully implementing NbS in the agri-food sector include planning, identification of synergies and trade-offs, technical assistance, policies and business models.

Making use of NbS tools can support the mainstreaming and uptake of NbS, ranging from methodologies, software, catalogues, repositories and e-platforms to guidelines and handbooks. NbS tools and data can make a valuable contribution to overcoming the barriers that hamper the wide uptake and implementation of NbS. We identified several NbS tools that can provide relevant data to policymakers, government officers, food companies, agricultural producers and other actors from the agri-food sector.

Realizing funding for NBS remains a challenge. Business Models can help identify the right stakeholders, beneficiaries and investors, and the necessary resources to implement NbS projects. As well, to assist agri-food businesses in identifying the added value of the NbS project and to communicate in a simple way what it is intended to do and why, who needs to be involved, and how to make it happen.

Some recommendations for further research and applications are:

- Having a universally agreed NbS definition is important for the application of measures and policy development worldwide. It is up to decision-makers and other stakeholders to decide on which NbS definition (gathered in this discussion paper as a guidance), is best to use. As mentioned before, the use of a NbS definition is often related to the purpose and context of the user, and/or the project and/or the geographical location. The EC, IUCN and the most recent UNEA definitions could be used for policy, research and practice for food systems.
- NbS use different types of measures and interventions that also support socio-cultural values. It is advised to embrace NbS principles (for nature protection, rehabilitation and management), but being aware that not all the interventions could be considered NbS.
- The NbS case studies show that every solution implies benefits and trade-offs at different levels of implementation. For new NbS projects, feasibility studies are recommended along with the identification of barriers,

opportunities and trade-offs. Cost-benefit and risk analysis are also recommended.

- For already implemented projects, it is suggested to evaluate the impacts of NbS in order to learn and optimize the approaches and solutions for new projects. It is important to consider different scales, geographical location, and climatic, environmental and socio-economic conditions.
- There is limited information on the potential to scale up (replication on similar contexts), scale out (scaling in a different context), and scale deep (transforming the system) of NbS case studies. Further research is recommended on the scaling dimension of NbS projects.
- It is suggested to strengthen partnerships between agri-food actors and public and private sectors, to ensure a common vision and long-term commitments towards NBS uptake in food systems.
- Apply participatory approaches that can help in the design and implementation of NbS and to increase acceptability.
- Use local knowledge for NbS projects. Stakeholders have different views on problems and therefore on solutions.
- It is recommended to strengthen the skills and knowledge sharing of different stakeholders to incentivize a mindset change and to achieve successful NbS implementation.
- Use the tools presented in this discussion paper to identify and assess possible suitable NbS. Potentially valuable tools can be missing or underrepresented as a result of the quick search and selection criteria. Therefore, to learn more about the different NbS tools to support the agri-food sector, further research is recommended.
- Make use of the NbS Business Model Canvas to present the socio-economic benefits of NbS projects, to obtain the support of the right stakeholders and investors, and to convert such NbS projects into partly or fully self-sustaining businesses.
- Even though there are plenty NBS projects intended for food production in the Netherlands, Europe and in the global south, some projects might not receive enough investment (or still seeking funding) despite their potential to generate financial, social and environmental returns. It is recommended to unlock investments by exploring possibilities in policy to mainstream NbS and to organize region-specific financing strategies.

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Appendix

Annex 1: Four high-level guidelines for successful nature-based solutions

SI Table 1: Four high-level guidelines for successful, sustainable nature-based solutions agreed on by a large community of researchers and conservation and development practitioners in the UK. (Source: Nathalie Seddon, et al., 2021)

Guideline	Context
Guideline 1: NbS are not a substitute for the rapid phase out of fossil fuels and must not delay urgent action to decarbonize our economies.	NbS play a vitally important role in helping to mitigate climate change this century, but their contribution is limited by a finite land area and is relatively small compared to what can be achieved by the rapid phase out of fossil fuel use. Furthermore, unless we drastically reduce GHG emissions, global heating will adversely affect the carbon balance of many ecosystems, turning them from net sinks to net sources of GHGs.
Guideline 2: NbS involve the protection and/or restoration of a wide range of naturally occurring ecosystems on land and in the sea.	All ecosystem types hold opportunities for NbS to enhance provision of ecosystem services to people. Management at the landscape scale, accounting for and utilizing interactions between ecosystems, can maximize long-term benefits. It is especially urgent to prevent inappropriate tree planting on naturally open ecosystems such as grasslands, savannahs and peatlands, or in areas with native forests. NbS must be valued in terms of the multiple benefits to people, rather than overly simplistic metrics such as numbers of trees planted.
Guideline 3: NbS are implemented with the full engagement and consent of Indigenous Peoples and local communities, including women and disadvantaged groups, and should be designed to build human capacity to adapt to climate change.	Robust social safeguards must be applied, to recognize, respect and reinforce human rights (including land/ecological and cultural rights), and support livelihoods. Just institutions will support larger scale, sustainable and more resilient NbS, at a crucial moment for the global response to climate change.
Guideline 4: NbS sustain, support or enhance biodiversity, that is, the diversity of life from the level of the gene to the level of the ecosystem.	Biodiversity plays a vital role in the healthy functioning and resilience of ecosystems. It secures the flow of essential services now and into the future, reduces trade-offs among them (e.g. between carbon storage and water supply) and helps to build human capacity to adapt to climate change in urban and rural areas.

Annex 2: Definitions of nature-based solutions and commonly used terms and approaches

SI Table 2: Definitions of nature-based solutions and commonly used terms and approaches that fall under the umbrella of NBS, as well as key concepts associated with NBS. This is not an exhaustive list. (Adapted from (Seddon et al., 2020))

Term (acronym)	Definition	References
Nature-based solutions (NbS)	Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits.	(Cohen-Shacham et al., 2019) IUCN (2012)
	Nature-based solutions aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes.	European Commission (2015)
Terms encompassed by nature-based solutions		
Ecological engineering	The design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both.	Mitsch and Jørgensen (2003); Odum (1962)
Ecosystem-based adaptation (EbA)	The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change.	CBD (2009)
Ecosystem-based disaster risk reduction (eco-DRR)	The sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development.	Estralla and Saalismaa (2013); PEDDR (2010)
Green/blue infrastructure (GI/GBI/BI)	A strategically planned and managed, spatially interconnected network of multi- functional natural, semi-natural and man-made green and blue features including agricultural land, green corridors, urban parks, forest reserves, wetlands, rivers, coastal and other aquatic ecosystems.	European Commission (2013)
	An integrated network of natural and semi-natural areas and features, such as urban green spaces, greenways, parks, rain gardens, greenways, urban forestry, urban agriculture, green roofs and walls, etc.	De la Sota et al. (2019)
Integrated land management (ILM), Sustainable land management (SLM), Catchment management and the Ecosystem approach	Various approaches to managing whole landscapes sustainably, with participation by all stakeholders.	CBD (2000); Reed et al. (2017); Rollason et al. (2018); Thomas et al. (2018)

Agroforestry, including silvo- arable and silvo-pasture	The practice of planting trees on farmland, including as rows between crops, or as shelter for livestock.	Torralba et al. (2016)
Agro- ecology, conservation agriculture and organic agriculture	Various approaches to sustainable agriculture that aim to protect soil health.	Warren et al. (2008)
Forest and landscape restoration (FLR)	A process that aims to regain ecological integrity and enhance human wellbeing in a deforested or degraded forest landscape.	Maginnis and Jackson (2012)
Reduced emissions from deforestation and degradation+ (REDD+)	Reducing Emissions from Deforestation and forest Degradation, and fostering conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries.	REDD+ ‘rulebook’, also known as the Warsaw Framework for REDD (UNFCCC, 2016); Paris Agreement (Article 5); (UNFCCC, 2015)
Natural climate solutions (NCS) or Nature-based Climate Solutions (NbCS)	Conservation and management actions that reduce greenhouse gas (GHG) emissions from ecosystems and harness their potential to store carbon.	Griscom et al. (2017)
Key concepts associated with nature-based solutions		
Blue Carbon	Organic carbon that is captured and stored by the oceans and coastal ecosystems, particularly by vegetated coastal ecosystems: seagrass meadows, tidal marshes and mangrove forests.	Macreadie et al. (2019)
Natural capital	Elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions.	Janssen et al. (2020); NCC (2014)
Ecosystem services (ES)	The benefits provided by ecosystems that contribute to human wellbeing.	Millennium Ecosystem Assessment (2005)
Nature's contributions to people (NCP)	All the positive contributions, or benefits, and occasionally negative contributions, losses or detriments that people obtain from nature.	Díaz et al. (2018)
Nature's contribution to adaptation (NCA)—formerly referred to as adaptation services	Properties of ecosystems that provide options for future livelihoods and adaptation to transformative change.	Colloff et al. (2020)

Annex 3: Extra case studies of nature-based solutions

SI Figure 1: Selected NbS case studies that demonstrate ranges of practices, benefits and approaches (FAO, 2021b).

	Practices	Scale	Benefits	Replicability
NAIROBI WATER FUND Watershed management for healthy forests, agriculture, water quality and hydropower	▪ Riparian management/ buffer zones ▪ Agroforestry adoption ▪ Terracing of hill slopes ▪ Reforestation for degraded lands ▪ Grass strips in farmlands ▪ Road erosion mitigation ▪ Soil conservation and water harvesting	**1 million-hectare** watershed that supplies 95 percent of Nairobi's drinking water, provides food for millions of Kenyans, and provides 65% of the country's hydropower.	A $10m investment over 10 years would yield $21.5M in economic benefits, including up to $3m/yr in increased yield for farmers, over $600k/yr increase hydropower revenue, and a 50% reduction in sediment concentration.	Currently there are 41 water funds in 13 countries, and over 80% of cities globally can meaningfully reduce sediment or nutrient pollution through Ag NbS.
COLOMBIA SILVOPASTURE Using silvopastoral practices to help ranching and ecosystems	▪ Scattered trees in pasturelands ▪ Timber plantations with livestock grazing areas ▪ Pastures between tree alleys, windbreaks, live fences and shrubs. ▪ Fodder banks	This project was developed in **87 municipalities** (12 states) in Colombia covering a total area of 159,811 hectares.	▪ 20 percent increase in milk and/or beef production. ▪ Improved management on 94,864 acres and protected 44,000 acres ▪ Reduction of 1.5 million tons of GHG emissions	These practices could be deployed in cattle ranching across Colombia with scaling up to 1M Ha by 2030. Could also reduce grazed area by 30% for conservation or other purposes.

	Practices	Scale	Benefits	Replicability
ECOSYSTEM SERVICE MARKETPLACE CONSORTIUM Developing markets to enable farmer adoption of NbS	▪ No-till or conservation tillage ▪ Cover crops ▪ Rotational Grazing ▪ Crop rotations ▪ Water use efficiency	ESMC currently conducting pilots in key agricultural regions, including great plains, corn & soy belt, and California fruit and nut.	Market value of quantified ecosystem benefits could be as high as $13.9 billion, by reducing C emissions by 190m MT, N runoff by 1.6b pounds, and P runoff by 0.8B pounds.	Goal is to launch a fully functioning national scale ecosystem services market to sell both carbon and water quality and quantity credits for agriculture by 2022.
QIANDAO WATER FUND Innovation plus tradition to engage small holder farmers	▪ Cooperative application of fertilizer and pesticide ▪ Mulching and burying fertilizer ▪ Cover crops ▪ Planting nectar source plants	Qiandao Lake watershed is key drinking water source in Yangtze River Delta and for Hangzhou metro area. Targeted sub-watersheds to deploy BMPs on 333ha in 2020.	▪ Reduced loss of nitrogen and phosphorus by 35-40%. ▪ Increased farmer income by 30-40% for green tea.	Currently expanding BMPs to broader scale in watershed and exploring other opportunities for Water Fund model in China.

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