Ref. Ares(2023)5294971 - 31/07/2023

Report on interdisciplinary conceptual and methodological approaches

30 July 2023

Deliverable D1.3 (version 4.0)

Funded by the European Union

Project name	**Transformation for sustainable nutrient supply and management**
Project acronym	**trans4num**
Project ID	101081847
Project duration	December 2022 – November 2026
Project Coordinator	University of Hohenheim (UHOH)
Project website	https://trans4num.eu/
Work package	1
Work package leader	SZE
Deliverable number and title	1.3 Report on interdisciplinary conceptual and methodological approaches
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Version	4
Dissemination level	PU Public

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1. Introduction

Healthy ecosystems and biodiversity are essential for the functioning of our society and economy. The loss of these natural resources reduces our ability to address major challenges such as climate change. Nature-based Solutions (NBS) refers to actions that conserve, manage, and restore natural and modified ecosystems in ways that address these challenges. This term builds on the longstanding recognition of our dependence on nature. The value of NBS is increasingly recognized at all levels, as evidenced by growing commitments and support from countries and organizations worldwide[1]. The multilaterally agreed definition of NBS, agreed at the May 2022 United Nations Environment Assembly (UNEA)[2], by 193 Member States, provides a foundation for a common understanding. The concept is widely used in development and nature-related fields. Globally, there are multiple interventions labelled as NBS and learnings have started to emerge[3]. Improving our understanding of the opportunities, challenges, trade-offs, and risks associated with NBS is essential for creating successful projects and promoting the global green transition. Understanding the potential for and developing interdisciplinary and transdisciplinary approaches is a key aspect of this process. This project deliverable 1.3 aims to get a better common understanding of how we in the Trans4num project addresses NBS from an inter- and transdisciplinary perspective and how we can develop nested frames and approaches for the interdisciplinary analyses of NBS across sites and scales.

1.1 Objectives of Trans4num - from task 1.1 to task 1.2

The overarching ambition of trans4num is to substantiate and broadly promote the NBS approach for sustainable agricultural practices in Europe and China with a particular focus on nutrient management (bio-based nutrient sources, sustainable crop rotations, integrated nutrient management practices, etc.). As part of the projects first six months the consortium partners have been discussing and tried to find common understandings of conceptual grounds.

In Work Package 1 (WP1) and task 1.1. and as part of deliverable 1.1 *Report on conceptual grounds and common understandings* the state of art in understanding NBS and related fields was reported (Vér et al. 2023). The aim of 1.1 was to facilitate a better understanding between partners on different conceptual grounds for NBS. The findings from task 1.1. shows that NBS as an emerging scientific concept, still deals with many parallel, sometimes contradictory, or unresolved, uncertain information about the concept of NBS (Vér et al. 2023). However, through inputs from task 1.1, a series of Trans4num webinars[4] in the winter and spring of 2023, and a final webinar titled "*Trans4num NBS Webinar - Discussion Session - a common basis for understanding nature-based solutions*", a shared basis for understanding NBS was discussed and agreed upon. The Trans4num project focuses

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[1] See e.g., "UNEP and Nature-based Solutions" https://www.unep.org/unep-and-nature-based-solutions
IUCN "Nature-based Solutions" https://www.iucn.org/our-work/nature-based-solutions, University of Oxford Nature-Based Solutions Initiative (naturebasedsolutionsinitiative.org) and EU Nature-Based Solutions Initiative (naturebasedsolutionsinitiative.org)

[2] UN Environment Assembly 5 (UNEA 5.2) Resolutions | UNEP - UN Environment Programme

[3] See e.g., "Nature-based Solutions: Opportunities and Challenges for Scaling Up" UNEP October 2022.

[4] In section 2, results from the webinars are presented.

exclusively on the agricultural interpretation of NBS, with an emphasis on nutrient management related NBS, including agroecology/agroecosystems and regenerative or circular farming. Other concepts, such as restoration ecology and organic farming, which also apply NBS, are considered as affiliated cases. Figure 1. was developed as part of this process.

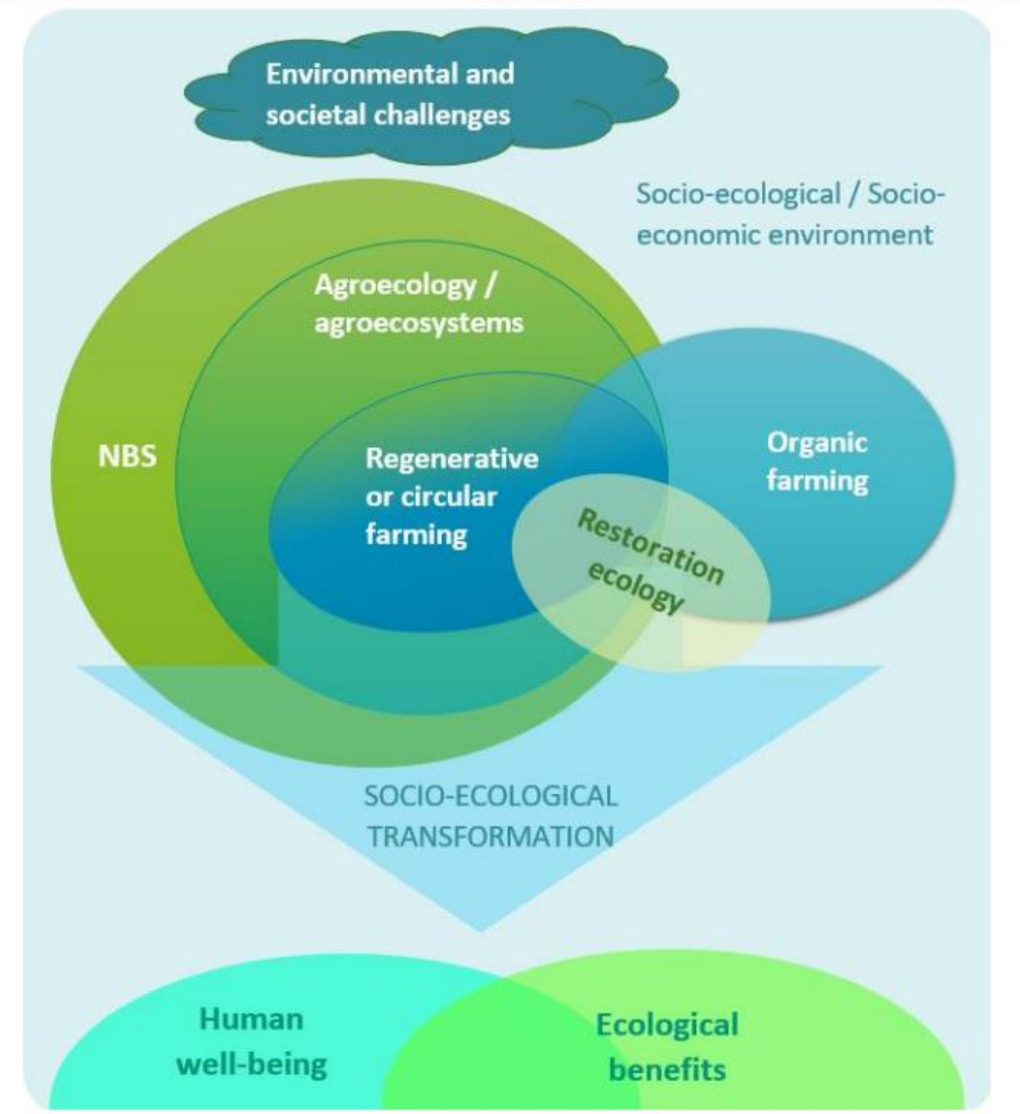

FIGURE 1. CONCEPTUAL FRAMEWORK OF NBS IN AGRICULTURE UNDER THE AUSPICES OF THE TRANS4NUM PROJECT (VÉR ET AL. 2023). THE FIGURE INTERPRETS NBS IN THE SOCIO-ECOLOGICAL AND SOCIOECONOMIC CONTEXT AS PART OF THE TRANS4NUM PROJECT.

1.2 Objectives of task 1.2

Implementing NBS is a complex process and requires a comprehensive concept for intentional change at various societal levels of decision making and intervention. In other words, a shift towards NBS in agricultural nutrient management implies a transformation of practices not only in agriculture and at producers but equally along value chains and among various other societal groups (e.g., functionaries, citizens, companies, consumers etc.). As a basis, a nested conceptual framework is necessary which allows for a broad scope of research and assessment on the inter- and transdisciplinary dimensions of the issue (Knierim et al. 2018). A systems approach is appropriate for studying situations that are adaptive and dynamic. The methodological core of trans4num is the development, adjustment, testing and upgrading of sustainable nutrient supply and management innovations. Trans4num will develop and implement a social-ecological transformation (SET) approach tailored for the inter- and transdisciplinary research on NBS for more sustainable nutrient management in regions with intensive farming systems.

In task 1.2 *Develop nested frames and approaches for the interdisciplinary analyses of NBS across sites and scales*, the objective is to build upon and differentiate the conceptual framework of task 1.1. An important step in this direction was the conduct of a series of webinars from March to May 2023 that showed a range of approaches towards and practices of NBS. Task 1.2 will develop joint understandings of the approaches for the interdisciplinary analyses of NBS across sites and scales. Given the biophysical, agronomic, socio-economic and socio-cultural uncertainties related to NBS and the social complexity of their implementation that differ across scales and in the course of time, the consortium partners will tailor, and adjust the joint scientific approach to the NBS site analyses. The outputs of task 1.2 will inform all trans4num NBS cases on how to design experiments, tools and models, in order to obtain results that correspond to expected internal and external use. The outputs will be disseminated to all science partners through a workshop/webinar.

This means the main objective of this deliverable 1.3 is to report on interdisciplinary conceptual and methodological approaches used in the four NBS sites in Denmark, Hungary, UK, and the Netherlands.

1.3 Purpose and development procedure of Deliverable 1.3

To achieve the objectives of task 1.2, we had to undertake a stocktake of how each partner/NBS sites were working inter- and transdisciplinary with their NBS innovations. The inputs from both the webinars and from a survey/excel spreadsheet distributed to all NBS site partners (see appendix), is used in this report as material to understand these approaches.

Development procedure

The deliverable was developed as part of WP1, D 1.3 (Report on interdisciplinary conceptual and methodological approaches) led by AU. The basic structure and contents of the document were defined by AU with the support of UHOH, RRes, CFS, WU, SZE, FiBL, P4All, CAAS, HAAS, SWU. This reporting was shaped through several online meetings and online webinars between the project partners, and the draft was uploaded to a common platform where partners could comment and add their input. The final document thus reflects the partners' shared insights on how they work interdisciplinary with their NBS interventions and is suitable for developing a common understanding that will guide the implementation of further project activities.

The procedure followed through online webinars and meetings a better understanding and clarification of analytical approaches and indicators for sites were developed. For this a survey/ distribution of excel spreadsheets to Trans4num partners was supplied. The partners were asked to fill in information, answer questions from all the four NBS sites and their NBS innovations. The aim was to collect information on the following questions:

- What do the partners understand with inter-disciplinary and/or and trans-disciplinary?
- How do the partners work inter-disciplinary and/or transdisciplinary in their NBS site.
- How are interdisciplinarity and/or transdisciplinarity used in the partner NBS site?

- What kind of data will be collected in the NBS sites, and how are they inter-disciplinary?
- What type of analytical approaches will be conducted?

These findings provide the conceptual basis for how we can develop joint approaches for the interdisciplinary analyses of NBS across sites and scales.

1.4 Structure of the document

The document is divided into 5 main sections. In the first introductory section we describe the aims of the trans4num project, the aims of task 1.2, the purpose of the document, the process of its development and its structure. The second section describes the results from the webinar series, where the purpose was to develop a common understanding of NBS innovations. Section three describes the four NBS sites and their NBS innovations. The fourth section explores Inter- and transdisciplinary studies in relation to NBS and nutrient management in a more general way. Sections 4.4-4.8 gives further insight into how the four individual NBS sites are undertaking inter- and transdisciplinary approaches and methodologies. Section 5 provides a summary of the reporting with conclusions and further work to be done.

2. Fostering a common understanding of NBS innovations

In total 9 webinars were held from March 15 to May 17, 2023. The overall aim of the Trans4num webinars was to set the bases for a common understanding of NBS from a nutrient management and agroecological perspective and with a specific focus on their potential to respond to challenges related to zero pollution. In particular, through consecutive sessions, the webinars gave consortium members insights into the existing practices and actions in the sites at farm and landscape levels. The webinars aimed to foster a comprehensive understanding of the NBS innovations and their potential to deliver transformative change.

The first webinar had a general introduction into the topic and related fields in agroecology. The following presentations of the webinars provided: 1) **the description of NBS actions applied in the NBS sites**, concerning agronomic, technological, socioeconomic, and cultural characteristics; 2) **the process of NBS implementation** and the involved actors, resources, knowledge and practical skills; 3) **clarifications on what challenges and how NBS respond to them.** The challenges addressed here include issues such as climate change (mitigation and adaptation), soil health, land degradation, water security, water pollution, food security, human health, biodiversity loss, and disaster risk management; 4) **what criteria are used to assess NBS performance**. This is vital to operationalize the definition and guide the evaluation of NBS. IUCN released a global standard that includes 28 indicators organized around 8 core criteria to deliver benefits for biodiversity and people, with a focus on ensuring a fair and equitable distribution of benefits (IUCN, 2020). In relation to the IUCN standard, we in the Trans4num project adapted our focus and developed the following criteria that are encompassed by the broader IUCN criteria:

- Halting pollution,
- Limiting N/P emissions,
- Restoring water, air and soil ecosystems,
- Promoting plant nutrition and health,
- Optimizing external nutrient inputs,
- Promoting soil health including carbon stocks,

- Advancing nutrient budgeting methodologies,
- Sharing organic wastes as new sources and pathways of nutrients,
- Improving awareness and uptake of knowledge and innovations.

5) **information on the type of implemented NBS actions.** Because NBS encompass a broad range of practices that can be deployed directly in the context of agricultural production and ecosystem management.

6) **on what level(s) are NBS actions implemented**, i.e., field/farm level, landscape/region/watershed level, and agri-food system/value chain level; 7) what **tradeoffs and synergies** are associated with the NBS action cross levels and over time, and; 8) **implementing institutions and country**, i.e., the name of associated institutions and the country where the NBS actions are implemented.

The webinar provided the project partners with vivid images and many concrete examples of how nutrient management related NBS are explored through plot and field experiments but also at regional/landscape and catchment levels. During the sessions, a large variety of NBS examples (e.g., fertigation in greenhouse horticulture, biofertilizers, landscape ecosystem management, novel crop rotation systems, agroforestry in the food system, and closing nutrient cycles) was presented and discussed. These examples show how NBS respond to the challenge of site-specific adaptability.

Concerning the focus on NBS in agriculture, the range within which we locate NBS is given by the following two definitions, namely

- NBS as "cost-effective interventions that can enhance resilience in agriculture and food production, while mitigating climate change and enhancing nature and biodiversity" (Iseman and Miralles-Wilhelm, 2021:6), in which neither the nature nor the scale of these interventions or practices is prescribed, and
- NBS is "the use of natural processes or elements" to improve "ecosystem functions of environments and landscapes affected by agricultural practices" by at the same time "enhancing livelihoods and other social and cultural functions, over various temporal and spatial scales" (Simelton et al., 2021:1).

Thus, there may be variation in how much food production is balanced with the ecosystem conservation and the provision of other ecosystem services in a given setting, in other words in how far NBS are 'nature-benefiting' vs 'nature-activating'. However, there is an interdependency between the two aspects, which needs to be recognised.

In trans4num, the focus is on effective and efficient nutrient management in intensive farming while also understanding the socio-economic perspective for integrated nutrient management. The following statements highlight different aspects of the NBS understanding and reflect the common lines within the consortium.

1. Nutrient management-related NBS is characterised by the application of various agronomic practices and their associated positive environmental (e.g., reduction of N- and P- surplus, of GHG emissions etc.) and socioeconomic (e.g., stabilisation or increase of crop yield and labour productivity) effects.

This statement falls short to highlight the dimension beyond farm boundaries, e.g., the role NBS plays within a value chain**. A complement is necessary as the above statement is not sufficient to characterise trans4num NBS.**

2. Nutrient management-related NBS is based on the idea of local circularity, i.e., the application of adaptive agronomic practices that close a local 'nutrient cycle' while keeping crop yields and nutritional quality at equal or improved levels.

The guiding idea of circularity was highly appreciated (although the term may be cumbersome), and **the message of this statement was widely endorsed**, as complementary to the previous one. Nevertheless, questions were raised for the delimitation of the 'local' space (is local circularity a must, within what regional range? Can there be export? Is it about the cycling of local resources?), and the meaning of 'standard' in this field of work. Both terms need to be further specified, most likely depending on the NBS in consideration.

3. Nutrient management-related NBS does satisfy farmers' needs and impact positively or neutrally the agro-ecosystem; while, when upscaled beyond field level, they additionally offer services to the society.

This statement points more clearly to the ecosystem and societal dimensions of NBS, a concern frequently raised across the break-out groups. Thus, **it was agreed that the role NBS plays in the embedding ecosystem shall be made explicit.** Some partners proposed to use the IUCN approach in this regard which may be further explored.

Summarising, the understanding of **nutrient management NBS as a nested concept** that comprises the three statements above, and by this, is expressed at the field/farm level, within the embedding ecosystem and to the wider societal, socio-economic and cultural environment (e.g. with the value chain model, in rural-urban relations, with the AKIS concept etc.).

However, the webinars also provided new questions and discussion points, which will be studied in the next years with novel research. For example, when considering questions of spreading NBS as innovative practices among farmers and stakeholders along value chains, at regional and landscape scales and within social systems, it is important to identify key features and characteristics that overcome single events and reveal valid across cases and regional boundaries. Thus, the final webinar discussion session proposed to discuss and agree on the following questions, some of the questions were resolved at the webinar and in collaborative meetings, whereas others can be explored further in the NBS sites in this project:

• Which linkages exist between practices on sites and the given definitions?

• Which indicators to focus on?

• Which commonalities exist among trans4num sites?

• Are the preliminarily identified indicators (Table 1) appropriate to structure a systematic description? If not all, which indicators can be maintained and which ones to be replaced?

Table 1. Indicators for framing site-specific practices to NBS (used in the NBS Webinar Call)

1) Agro-and socioeconomic characteristics	2) Stakeholder & input	3) Challenges addressed	4) Performance criteria	5) Trade-offs	6) Level(s)	7) Implementing institutions

Other open points, further discussions, from the exchange, also several open points resulted. These are:

- A general mismatch of the language used for communication with actor groups other than scientists was observed; this needs to be modified for DEC purposes;
- More ambition should be vested in biodiversity and ecosystem services concerns;
- (How) Does the current understanding differ from a general sustainability approach?
- What and how to capture economic and societal dimensions?

It was agreed that:

- Technologies (e.g., DSS) are drivers and support to NBS, and not seen itself as an NBS.

The exchange of these questions and the discussions at the webinars created a (more) harmonised understanding of the commonalities and specificities of the trans4num NBS but also laid the bases for deliverable 1.3. The discussions at the webinar helped develop the indicators and a new table was co-developed. See table A1 in appendix.

3. NBS Characterisation in Denmark, Netherlands, UK, and Hungary

On each of the NBS sites (in Denmark, Hungary, The Netherlands and in UK) the partners responsible for NBS sites have selected, have begun to test and are studying NBS innovations with a system approach thereby allowing to define, monitor, and assess the effects at field/local, farm, landscape, and regional level - embracing them as a nested, multi-level social-ecological system in transformation.

In all sites, experimental farms will serve as focal points where a) agronomic field-level trials are used to generate data for the monitoring and assessment of nutrient management, and a) workshops, demonstration events, field days and excursions are used to obtain practice users' appraisals and socio-economic data on NBS.

Academic NBS sites coordinators and farm managers, farmers organisations and related stakeholders will work in close cooperation guided by a mix of applied natural and social sciences methods and elements of networking and facilitation.

All insights from the NBS sites' activities will be documented in yearly reports (D2.2-D2.8). Additionally, for one or several selected NBS cases per site, an AKIS analysis will be conducted with empirical social research (D2.9). All results will have stand-alone character per site and feed into dissemination activities, but equally be part of the qualitative comparative assessment of NBS innovation processes across sites (D4.4).

In this section, first we will describe each of the individual NBS sites and secondly discuss how the partners are working inter- and/or transdisciplinary.

In table 2. the NBS sites and their biophysical and environmental characteristics are presented.

TABLE 2. PRESENTS A BROAD OVERVIEW OF THE FOUR (FIVE) DIFFERENT NBS SITES AND THEIR BIOPHYSICAL AND ENVIRONMENTAL CHARACTERISTICS.

Biophysical and environment characteristics of each NBS Site						
NBS site	**Location**	**Climate**	**Soil type - and fertility**	**Elevation range (m)**	**Precipitation/yearly**	**Which data on weather data are you collecting? Or do you have access to local weather data?**
Danish	*Limfjord*	*Temperate climate*	*Sandy Soils - High Fertility*	*0-60m*	*800 mm - 175 rain days*	Access to regional and local weather data
Hungarian	*Kimle*	*Temperate climate*	Fluvisols – High Fertility	0-0.5 m	450 - 550 mm	Access to regional and local weather data + weather station on the field
Rothamsted Research, Large-Scale rotation experiment (LSRE)	*Rothamsted sites at Brooms Barn, Suffolk and Harpenden, Hertfordshire*	Temperate climate	Sandy Loam + Clay Loam - High Fertility	Harpenden: 120m, Brooms Barn: 60m	Harpenden: 760mm Brooms Barn: 640mm	Local meteorological station at each site
Devon U.K.	*Rothamsted North Wyke site*	*Oceanic temperate*	*Vertisol soil / Mineral rich - High Fertility*	*180m*	*1034-1043mm/year - 250 rain days/year*	*Access to U.K. Meteorological Office weather data*
Netherlands	*Kollumerwaard*	Temperate climate	Light clay soils	Positive 0,7 to positive 1 meter	850-900mm - 192 rain days	Access to weather forecast and weather stations on farm level
Netherlands	*Ebelsheerd*	Temperate climate	Heavy clay soils	negative 0 to negative 1 meter	800-825 - 192 rain days	Access to weather forecast and weather stations on farm level

In the following sections, the four NBS sites will be described in more detail.

3.1 The Danish NBS site

Written by Mette Vestergaard Odgaard and Morten Graversgaard, inputs from Anne Mette Langvad

Denmark is situated in the Atlantic lowland region of northern Europe dominated by intensive agriculture. The main land use is agriculture which covers 61%. Nature covers 25% in total and 13 % is forest (Levin et al 2018) (Table 3).

TABLE 3. LAND USE FOR THE NSB SITE AND TOTAL FOR DENMARK AT NATIONAL SCALE AND PERCENTAGE OF THE TOTAL SITE AREA AND DANISH AREA.

Land-use type	Land use (ha)			
	Denmark	Denmark (%)	Site[1]	Site (%)
Urban	591517.6	14.0	26722.7	10.3
Agriculture, intensive	2370193.6	56.0	148846.7	57.5
Agriculture, extensive	187004.1	4.4	13326.1	5.1
Agriculture, not classified	21444.2	0.5	1053.6	0.4
Forest	562381.2	13.3	36901.9	14.2
Nature, dry	150234.6	3.6	10653.2	4.1
Nature, wet	235060.1	5.6	15148.2	5.8
Lake	71957.1	1.7	4141.4	1.6
Stream	40277.8	1.0	2210.3	0.9
Total	4230070.3		259004.0	

[1] The NBS site drains into Bjørnholms Bugt, Riisgårde Bredning, Skive Fjord, Lovns Bredning and Hjarbæk Fjord

Despite an overrepresentation of agriculture, the Danish landscape shows a significant geographical variation in other geophysical, hydrological and landscape elements such as nitrogen retention, costal nitrogen (N) loads, soil types, soil organic carbon, biodiversity, and farm type and practices. At Danish research institutions and public administrative agencies these geographical data exists, open source, in a relatively fine resolution, which strengthen the possibilities for conducting landscape analysis and enables a more targeted implementation of NBS for the benefit of aiming at zero pollution. The chosen Danish NBS site is situated in Northern Jutland and represents part of the Limfjord catchment, which connects the North Sea and the Kattegat (Figure 2), and covers an area of 260,000 ha where approximately 63% is agriculture (Table 3). The land use of the NBS site resembles average national land use (table 3, Figure 2).

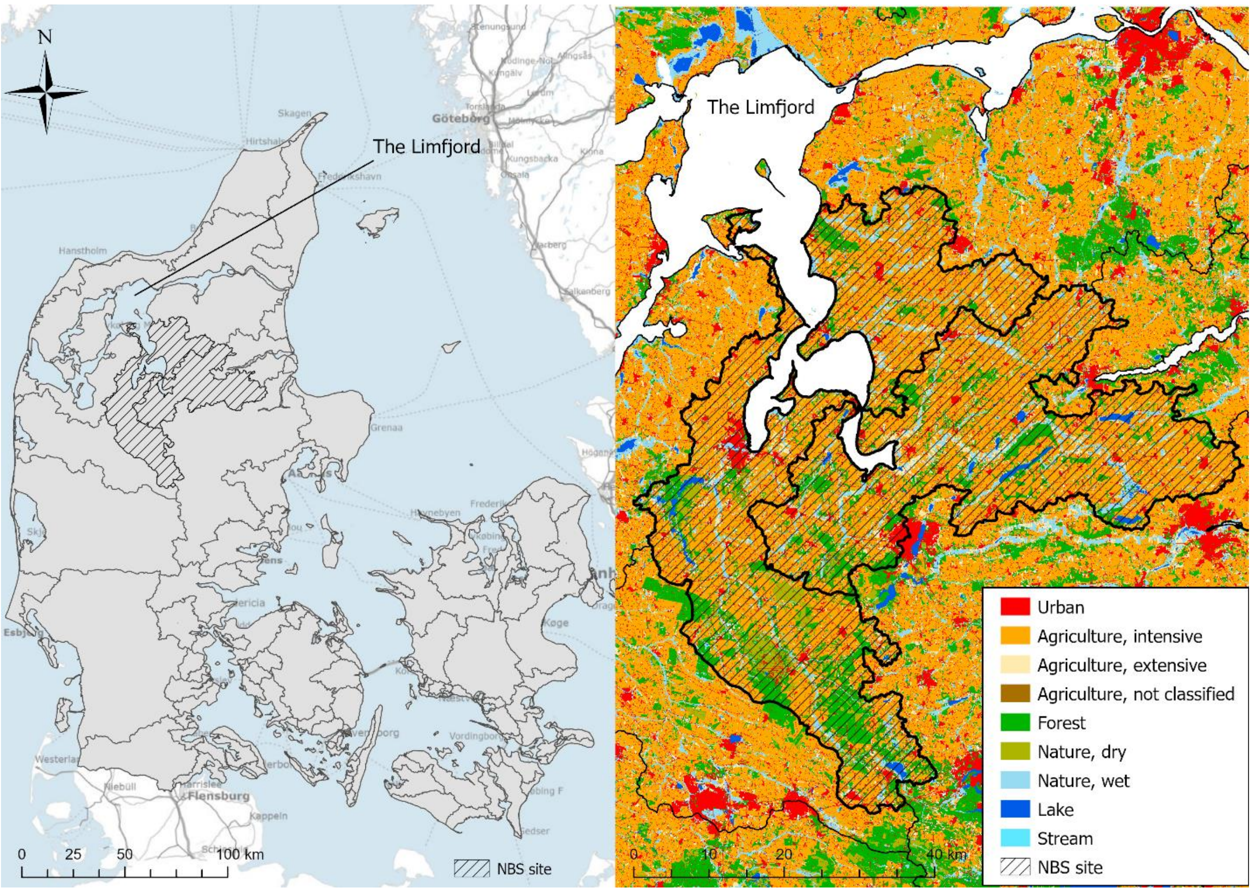

FIGURE 2. OVERVIEW OF THE NBS SITE LOCATION IN DENMARK (LEFT) AND ZOOM OF THE NBS SITE WITH OVERLAY OF LAND USE (LEVIN ET AL 2018) (RIGHT).

FIGURE 3. LOCATION SALLING: HAGENSHOEJ AT THE LIMFJORD. *ACCREDITATION PHOTO: THOMAS KØSER, SKIVE MUNICIPALITY*

Furthermore, the site partly covers the national range of both biodiversity scores (0-16 score – where 20 is the highest at national level) as well as N retention percentages (5-100%), which makes the site a well representation of the Danish region. Still, the Limfjord represents a catchment with some of the poorest water quality and ecological status and thus a higher nitrogen reduction goal relative to the rest of Denmark to fulfill the goals of the European Water Framework Directive are needed. With a national costal N reduction goal of approximately 13,000-ton N/yr by 2027, approximately 28% of this is to be reduced from the catchment surrounding the Limfjord and half of this should be reduced from the chosen NBS site (1500-ton N/yr). A key conclusion from previous investigations on policy implementation in Denmark shows that it will not be possible to reduce these amounts of N by implementing only collective measures such as constructed wetlands (SEGES, 2017). There is a need for a combination of measures and a higher level of stakeholder involvement if the goals are to be delivered. One solution of setting aside large amounts of agricultural land could compromise the economic profit of agricultural areas (Ørum et al., 2017), and are therefore not seen as a plausible solution. Therefore, innovative NBS that are targeted individual catchments with the involvement of relevant stakeholders are needed for socio-ecological transformation.

The Danish partners will assess the NBS from a systems approach thereby allowing us to define, monitor, and assess NBS effects at field/local, farm, landscape, and regional level - embracing the whole system. For the Danish site we select 2 NBS: 1) Changes in crop rotations (Circular and N crop-rotation) towards more biomass crops, including perennial crops, e.g. grass production (Figure 4) and grass clover mixtures (Figure 5) for biorefinery purpose to produce protein to feed monogastric animals and fiber for ruminants (Hermansen et al., 2017; Børgesen et al., 2018).

FIGURE 4. FARMING LANDSCAPE, SALLING. *ACCREDITATION PHOTO: THOMAS KØSER, SKIVE MUNICIPALITY*

A replacement of cereal with grass will facilitate changes in field and crop rotations (local level) and influence farm nutrient balances, local climate accounts, and potentially benefit positive effects in surrounding nature areas and the aquatic environments such as the Fjord (Figure 3) (landscape/regional level) (Odgaard et al., 2019b). Furthermore, other farm types using the biorefinery products will also be influenced (system level). 2) Biobased fertilizer from organic waste. Use of biobased fertilizers from manure and other waste streams in replacement of chemical fertilizers will increase the circular use of nutrients and potentially decrease N loss to the environment while enhancing the farmer's profit. Hence, these NBSs both fit well with the general definition of NBS from

IUCN as being: "*Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature*". And with the definitions as part of the Trans4num project.

FIGURE 5. LOCATION SALLING: HJERK, GRASS AND CLOVER MIX NO. 46. PHOTO *ACCREDITATION: LISBET RAUFF, KLIMAFONDEN SKIVE.*

A targeted approach can be used to distribute the various NBS most effective across the landscape (landscape/regional level). Hence, the selected NBS can embrace local to regional level effects, depending on the research design. The potential of each NBS to facilitate a more sustainable production will be assessed through desk studies, modelling activities, and interviews. Furthermore, their implementation is discussed with relevant practitioners and evaluated though societal transformation scenarios. The effect of the selected NBS will be monitored using e.g. remotely sensed data and machine-learning methods. Implementation of these NBS potentially also have positive impacts on soil, climate and biodiversity while also delivering positive effects on rural communities and local economies (Odgaard et al., 2019ab).
The practical partner aligned for the Danish NBS sites and region are Klimafonden Skive, ICOEL (Organic Innovation Center Denmark) and FieldSense (Cordulus) a SMV with expertise in remote sensing for the monitoring and optimization of nutrient flows from NBS. While the scientific partner is Department of Agroecology, Aarhus University.

In the Danish site, two NBS innovations will be tested and demonstrated. In table 4-7. A NBS inventory with key information on challenges addressed, the plan for implementation, etc. This information is taken from the surveys each NBS partner filled out.

Table 4. summarizing NBS, the challenges addressed, and the synergies obtained Denmark

Country and NBS	Challenge(s) addressed with NBS	Synergies beside directly addressed challenges
Denmark		
Biomass crops, including perennial crops, e.g., grass production with novel crop rotations for biorefinery purpose	Nutrient challenge (focus on N) to comply with regulation (Water Framework Directive). To reduce nitrate leaching while producing "green" protein to feed monogastric animals and fiber for ruminants). Reduced nutrient leaching to comply with the needs of the water environment (not only policy objectives). To reduce nitrate leaching in an economically viable way for farmers and related industries while taken into consideration how to maximize biomass resource efficiency (through business symbiosis). (Hypothesis: Economic viability to accelerate the change needed for change to come).	By applying biomass crops - we expect to obtain increased carbon sequestration in agricultural soil, improved soil micro-biodiversity in soil and increase insects and pollinators communities. Positive biodiversity effects (grass support stronger biodiversity as compared to cereals). Positive effects in climate (grass store more carbon that cereals). Higher nutrient densities, perhaps included in one PhD project. We are using grass as protein because it has high protein amounts. Closing nutrient loops with NBS implementation at local and regional scale through exchange of nutrients/biomass in the biomass chain.
Bio-based Fertilizer	As an extension to the above: Through industrial processing of green biomass to protein, biogas and biobased fertilizer export nutrients from one field not in need of additional N (and P) to fields in need of additional N (and P) due to the grass-based fertilizer)	

TABLE 5. SERIES OF QUESTIONS RELATED TO THE TYPE OF NBS AND CHALLENGES ADDRESSED.

Your site/NBS description	Which NBS do you work with at your site?	Which challenge(s) do you address within the NBS site?	By the end of the project which specific measurement(s) or outcomes will determine your success in addressing this/these challenge(s)	By applying your NBS which bio-geo-physical synergies are likely to be obtained besides the challenge(s) directly addressed?	Which synergies besides the challenge(s) directly addressed will you measure as part of this project	What other NBS could potentially be relevant for your NBS site addressing the same challenge?
Danish NBS intervention example	**Biomass crops:**		**Engagement of stakeholders in planning biomass supply systems for NUE, improvement of N reduction strategies using NBS in the recipient Fjord:**	**By applying biomass crops the following is envisioned:**	**None planned but could change dependent on PhD's project proposals:**	
	● **1)** Perennial crops, e.g. grass production adoption.	● **1)** Reduce nitrate leaching.	● **1)** Improved understanding of the biomass chain (structural, social and economic).	● **1)** increased carbon sequestration in agricultural soil.	● **1)** Possibly use existing standard numbers on biodiversity and carbon effects.	**Finding alternative green proteins:**
	● 2) Novel crop rotations.	● **2)** Producing "green" protein to feed monogastric animals and fibre for ruminants.	● **2)** Improved understanding of the farmers perception of the NBS.	● **2)** improved soil micro-biodiversity in soil.	● **2)** Food density could equate to improved NUE if combining it with N-Footprint.	● **1)** Biobased fertilizers from grass pellets.
	● **3)** Biorefinery production/adoption objectives.	● **3)** Farmer engagement for nutrient export between farmers.	● **3)** Data on amount N reduction in the recipient area after implementation of the NBS.	● **3)** Increase insects and pollinators communities. Positive biodiversity effects (grass support stronger biodiversity as compared to cereals).	● **3)** One PhD project aim to "measure" circularity in the region on biomass flows under different scenarios of NBS implementation.	● **2)** agro-forestry, etc

			• **4)** Exchange system amongst stakeholders exporting nutrients/biobased fertilizer from fields with no additional nutrient needs to fields in need.	• **4)** Positive effects in climate (grass store more carbon than cereals).			• **1)** Catch crops (The green part of sugar beets etc).
			• **5)** Investments or future investment plans with respect to green biorefinery production.	• **5)** Higher nutrient densities, perhaps included in one PhD project.			• **2)** CBIO has been working with protein extraction and biogas from sea-lettuce. This could be explored in terms of circularity moving surplus nutrients from the fiord to the field.
				• **6)** We are using grass as protein because it has high protein amounts.			
				• **7)** Closing nutrient loops with NBS implementation at local and regional scale through exchange of nutrients/biomass in the biomass chain.			

TABLE 6. SERIES OF QUESTIONS RELATED TO THE SCALE OF INTERVENTION, INTERVENING ACTIVITY, DATA MEASUREMENT AND MEASUREMENT PLAN.

At which geographical scale(s) do you work with your NBS (e.g. farm, catchment, local, regional scale)	What is the size of your NBS site? (ha, km2)	Please list data collection periods planned for, including time and time span for each data collection
This NBS fits all scales: ● **1)** It is implemented on fields belonging to farms affecting neighbouring farms and landscapes. We will analyse all scales.	**260000+ Hectares will be in use** ● **1)** Model grass crop scenarios for 260000 Ha. ● **2)** Biorefinery biobased fertilizer will be produced/ Model for 260000 Ha ● **3)** A system for exporting N by way of biobased fertilizer from original 260000 Ha to x Ha in the surrounding area will be developed.	**Landscape modelling:** ● **1)** Register data from the Danish Agricultural Agency will be collected yearly. **Stakeholder involvement:** ● **1)** Following the stakeholder manual. We plan to involve local stakeholders in first year 2023 and then follow up with an engagement process of more frequent and active involvement

TABLE 7. SERIES OF QUESTIONS RELATED TO IMPLEMENTATION AND MAINTAINING OF THE NBS- GOVERNANCE ARRANGEMENTS.

Which stakeholders/ who will you directly involve in collection of the bio-geo- physical data?	Who will be directly responsible for implementing NBS at your particular NBS-site	Who will be needed to support the implementation of NBS at your particular NBS site	Where do you consider your NBS relevant to be implemented outside your particular NBS site?	Who will be directly responsible for implementing NBS in relevant areas outside your particular NBS site
• **1)** Farmers.	• **1)** Farmers and landowners will be directly responsible for implementing the NbS, biomass distribution.	• **1)** Farm advisors.	• **1)** All areas where there are currently cereals.	• **1)** Farmers.
• **2)** Satellite and weather data specialists.	• **2)** Companies/organisations will be responsible upscaling the NbS intervention	• **2)** Regulators.	• **2)** Where the biophysical traits allow for the biomass production.	• **2)** Satellite and weather data specialists.
• **3)** Agronomists/agronomic advisors.	• **3)** We as a consortium will be responsible for co-developing plans for "how to".	• **1)** Investors in biorefinery plants.	• **3)** Areas where nutrient surplus is a problem and in particular also areas where supply of protein is needed (for feed).	• **3)** Agronomists/agronomic advisors.
• **4)** Stakeholders from the biomass chain. E.g., biogas plants and biorefinery stakeholders.	• **4)** We might also be responsible for providing incentives	• **2)** Biorefinery technology owners.	• **4)** We will specify areas where biophysical traits allow for grass-based biomass production.	• **4)** Stakeholders from the biomass chain. E.g., biogas plants and biorefinery stakeholders.

● **5)** Municipality public servants.		● **3) B**iogas facilities. ● **4)** Regulatory bodies like the municipalities and the Agricultural agency most likely also symbiosis parks /farm symbioses		● **5)** Municipality public servants. ● **6)** Symbiosis is required with farmers supply organizations collaborating with investors that invest into biorefinery facilities themselves.

TABLE 7. Series of questions related to implementation and maintaining of the NBS - governance arrangements (continued)

Who will be needed to support the implementation of NBS in relevant areas outside your NBS site	Implementing institutions (formal or informal legal governmental structures and/or organisations will affect/influence implementation)	Responsible for data collection?
	We look at a whole chain perspective:	
● **1)** Farm advisors.	● **1)** Private companies / farmers owning biorefineries.	● **1) Landscape modelling:** We will use data received and polished by Aarhus University.
● **2)** Regulators	● **2)** Municipalities will be the implementing institutions.	● **2) Stakeholder involvement:** Project participants.
● **3)** Symbiosis is required with farmers supply organizations collaborating with investors that invest into biorefinery facilities themselves.	● **3)** For future implementation the Danish agricultural agency needs to Implement rules for grass as bases for crop rotation used for Biorefinery purposes	

3.2 The NBS site in the Netherlands

The Dutch NBS site is located in the north of the Netherlands in a UNESCO World Heritage site with special natural values and an important role in maintaining the hydrological balance of the region. Unfortunately, intensive agriculture in the region, primarily potato production (also cereals, horticulture crops and fodder), has also caused the depletion of soil fertility and reduced agricultural productivity. Farmers are looking for innovative NBS solutions to restore this lost productivity, as well as enhance the resilience and efficiency of their farms. In addition, the provincial government has a strong interest in implementing NBS innovations in line with their policies to encourage environmentally friendly, sustainable and resilient production systems.

Trans4num is testing the use of more natural approaches to crop nutrient management in three contrasting farming systems in the region:

An organic farming system with potatoes, wheat and carrots. Possible nutrient sources include grass-clover mixtures and lucerne etc., both for mulching and silage;

- A conventional farming system with wheat in rotation, and;
- A regenerative arable organic farming system with potatoes in rotation.

All field trials will be conducted on the SPNA Ebelsheerd and Kollumerwaard experimental farms. The SPNA researchers will collaborate with farmer groups at the study sites to design and test the NBS innovations and disseminate the results. Comprehensive soil and crop data will be collected from both sites for evidence-based decision-making.

The sites are:

SPNA Ebelsheerd

SPNA Ebelsheerd is located on heavy clay soils in a cereal-growing region. The experimental farm Ebelsheerd has both organic and conventional fields on a total area of 112 ha. The conventional crops grown are winter wheat, winter barley, rapeseed, onions, sugarbeet and lucerne. The organic crops grown are spring wheat, pumpkins and string beans. The NBS solutions will be trialled on 3 ha land.

SPNA Kollumerwaard

SPNA Kollumerwaard is located on reclaimed clay soils in a region growing mainly seed potatoes. The experimental farm also has both organic and conventional fields. The conventional crops grown are seed potatoes, sugarbeet, wheat and barley, and the organic crops are seed potatoes, carrots, oats, grass-clover mixtures, wheat and pumpkins. The NBS solutions will be trialled on 20 ha.

The cases include Cover crops in rotation with seed potatoes

Farmers in the north of the Netherlands are increasingly interested in cover crops to improve the production of high-quality seed potatoes. Cover crops have several benefits issues, including fulfilling the Common Agricultural Policy regulations, buffering uncertainties in the supply of fertilisers and improving soil quality. Farmers have their own preferences regarding which cover crops to sow but need more information on when best to destroy and incorporate them into the soil to optimise the availability of nutrients for the following potatoes. SPNA will research the availability of soil nutrients when the cover crop is destroyed at different times before sowing the seed potatoes.

This work will also include monitoring aphid populations since there is evidence to suggest different cover crops and other soil ameliorations can reduce aphid numbers and thereby enhance the efficiency of soil nutrient use.

Grass-clover mixtures in rotation with organic winter wheat

The heavy clay soils at SPNA Ebelsheerd are ideal for growing winter wheat. Organic winter wheat is mainly fertilised with animal manure; however, there are shortages of manure in the region and farmers are looking for alternatives. SPNA is therefore researching the use of grass-clover mixtures grown in rotation.

Lucerne and grass-clover pellets for fertilising winter wheat

Wheat production in the Netherlands is typically very intensive, with large inputs of mineral nitrogen fertilisers. Trials at SPNA Ebelsheerd will test the use of lucerne and grass-clover pellets (a form of biofertiliser) as an innovative alternative to the conventional use of mineral fertilisers. Comparison of the mineral and biofertilisers will include investigation of the impact upon both short- and longer-term soil nutrient status and crop yield and quality.

TABLE 8. SUMMARIZING NBS, THE CHALLENGES ADDRESSED, AND THE SYNERGIES OBTAINED THE NETHERLANDS.

Country and NBS	**Challenge(s) addressed with NBS**	**Synergies beside directly addressed challenges**
Netherlands		
Crop rotation, plant-based fertilizer (cut-/carry fertility, plant compost, plantary pellet et. al.)	Nutrient challenge (focus on N and P) to reduced nitrate leaching and improve soil P availability	By crop rotation and applying plant-based fertilizers- the GHG emission and nitrate leaching are expected to reduced, while the soil nutrient use efficiency is expected to increase. Improved soil structural stability will be expected due to the non-tillage in NBS trails. The exogenous nutrient (N/P) input will be reduced by closing nutrient loops, while chemical pesticides will be reduced due to the crop rotation practice. Finally, the biodiversity of agricultural ecosystem and soil health will be improved in NBS trails.
Plant based fertilizer and natural crop protection	Nutrient challenge, when using straw to reduce the availability of aphids on the field farmers needs more nitrogen to decompose the straw. The question is if grassclover and or fresh grass are giving the same effect or that the nitrogen use can be less due to the nutritional value of grass clover or fresh grass.	A strong reduction to no almost no use of aphid killers and oils to prevent the virus spread due to aphids. More healthy crops through a reduction of stress in the crop due to the chemicals normally used. Less use of fertilizers.

In the Netherlands site, a number of NBS innovations will be tested and demonstrated. In table 8-11. A NBS inventory with key information on challenges addressed, the plan for implementation, etc. This information is taken from the surveys each NBS partner filled out.

TABLE 9. SERIES OF QUESTIONS RELATED TO THE TYPE OF NBS AND CHALLENGES ADDRESSED.

Your site/NBS description	Which NBS do you work with at your site?	Which challenge(s) do you address within the NBS site?	By the end of the project which specific measurement(s) or outcomes will determine your success in addressing this/these challenge(s)	By applying your NBS which bio-geo-physical synergies are likely to be obtained besides the challenge(s) directly addressed?	Which synergies besides the challenge(s) directly addressed will you measure as part of this project	What other NBS could potentially be relevant for your NBS site addressing the same challenge?
Netherland Kollumerwaard NBS Plenty Organic	• **1)** Crop rotation. • **2)** Plant-based fertilizer (cut-/carry fertility, plant compost, plantary pellet et. al.)	**Nutrient challenge (focus on N and P):** • **1)** Reduced nitrate leaching. • **2)** Improve soil P availability	• **1)** Data on N reduction in the GHG emission and soil leachate. • **2)** Improvement on available P content in the soil system. • **3)** Better N/P use efficiency by target crops.	**By crop rotation and applying plant-based fertilizers:** • **1)** The GHG emission and nitrate leaching are expected to be reduced. • **2)** The soil nutrient use efficiency is expected to increase. • **3)** Improved soil structural stability will be expected due to the non-tillage in NBS trails. • **4)** The exogenous nutrient (N/P) input will be reduced by closing nutrient loops. • **5)** Chemical pesticides will be reduced due to the crop rotation practice. • **6)** Finally, the biodiversity of agricultural ecosystem and soil health will be improved in NBS trails.	N/A	N/A

Netherlands Kollumerwaard NBS Straw, grass clover, fresh grass aphids	• **1)** Plant based fertilizer. • **2)** Natural crop protection	**Nutrient challenge:** When using straw to reduce the availability of aphids on the field farmers needs more nitrogen to decompose the straw. **Hypothesis:** The question is if grass clover and or fresh grass are giving the same effect or that the nitrogen use can be less due to the nutritional value of grass clover or fresh grass.	• **1)** The nutritional value of the different products is known and it's also known if they give the same effects of straw on reducing aphids available in the field.	• **1)** A high reduction to almost zero use of aphid killers and oils to prevent the viral infection spread due to aphids. • **2)** Healthier crops through a reduction of stress in the crops due to the decreased chemical usage. • **3)** Reduced use of fertilizers.	**The use of nitrogen and phosphor**	N/A
Netherlands Kollumerwaard NBS Cover crop in a seed potato-based crop rotation	• **1)** Plant based fertilizer obtained from crops in the crop rotation	**Nutrient challenge:** We want to know when the best moment is to destroy a cover crop to provide the most nutrients for the crop.	• **1)** The best moment of destroying a cover crop is then known.	• **1)** Reduced use of fertilizers and an improvement of biodiversity. • **2)** An improvement of the nitrogen uptake out of cover crops during the growing season	**The use of nitrogen and phosphor**	N/A

Netherlands Ebelsheerd Pellets in Winter wheat		**Nutrient challenge:** We want to know if conventional fertilizers could be compared with plant-based pellets	• **1)** The nutritional value of the pellets is known.	• **1)** Reduced use of chemical fertilizer	**Reduced pollution outcomes**	N/A
Netherlands Ebelsheerd Grass clover in organic wheat	• **1)** Plant based fertilizer	**Nutrient challenge:** We want to know if conventional manure could be compared with standard organic manure.	• **1)** The nutritional value of the grass clover is known.	• **1)** Reduced use of manure	**Reduced pollution outcomes**	N/A

TABLE 10. SERIES OF QUESTIONS RELATED TO THE SCALE OF INTERVENTION, INTERVENING ACTIVITY, DATA MEASUREMENT AND MEASUREMENT PLAN.

Your site/NBS description	At which geographical scale(s) do you work with your NBS (e.g. farm, catchment, local, regional scale)	What is the size of your NBS site? (ha, km2)	Please list data collection periods planned for, including time and time span for each data collection
Netherland Kollumerwaard NBS Plenty Organic			**Soil samples:** Three sampling periods per year, Crop Samples & GHG and Leachate tests: ● **1) The 1st sampling period:** Before fertilization and pre-plant of crops; Done, timing known, before planting the potato before preparing the soil. ● **2) The 2nd sampling period:** Before-harvest of crops; Just before potato foliage removal. ● **3) The 3rd sampling period:** At the end of the year (winter). When cover crop growth is slowed down through low temperatures. Before removing/ destroying of the cover crop). ● **4) Crop samples:** Crops will be collected at the annual harvest. ● **5) GHG and soil leachate samples:** will be collected during the crop growth season. GHG will be sampled weekly. Soil leachate will be collected according to the rainfall.

Netherlands Kollumerwaard NBS Straw, grass clover, fresh grass aphids	**The trial is being implemented on the SPNA location Kollumerwaard:** ● **1)** The effect can be that all seed potato farmers will adopt this approach.	**0,6 hectare**	● **1)** Pre seeding potato. ● **2)** During growing season. ● **3)** After harvest.
Netherlands Kollumerwaard NBS Cover crop in a seed potato-based crop rotation	**The trial will be implemented at a farmer close by SPNA Kollumerwaard:** ● **1)** Farmers; ● **2)** Advisors; ● **3)** Company adoption envisioned.	**unknown jet**	**Collection Period:** ● **1)** Autumn; ● **2)** winter; ● **3)** pre season; ● **4)** In season and; ● **5)** After harvest
Netherlands Ebelsheerd Pellets in Winter wheat	**The trial will be implemented at a farmer close by SPNA Kollumerwaard:** ● **1)** Farmers;	**Plot size fields 3x10 meter**	**Collection Period:** ● **1)** Pre spreading.

	• **2)** Advisors; • **3)** Company adoption envisioned.		• **2)** during growing season. • **3)** After harvest
Netherlands Ebelsheerd Grass clover in organic wheat	**The trial will be implemented at a farmer close by SPNA Kollumerwaard:** • **1)** Farmers; • **2)** Advisors; • **3)** Company adoption envisioned.	**Plot size fields 3x10 meter**	**Collection Period:** • **1)** Pre spreading. • **2)** during growing season. • **3)** After harvest

Table 11. Series of questions related to implementation and maintaining of the NBS - governance arrangements.

Your site/NBS description	Which stakeholders/ who will you directly involve in collection of the bio-geo- physical data?	Who will be directly responsible for implementing NBS at your particular NBS-site	Who will be needed to support the implementation of NBS at your particular NBS site	Where do you consider your NBS relevant to be implemented outside your particular NBS site?	Who will be directly responsible for implementing NBS in relevant areas outside your particular NBS site	Who will be needed to support the implementation of NBS in relevant areas outside your NBS site	Implementing institutions (formal or informal legal governmental structures and/or organisations will affect/influence implementation	Responsible for data collection?
Netherland Kollumerwaard NBS Plenty Organic	• **1)** farmers, • **2)** researcher from WUR. • **3)** researcher from SPNA	**SPNA**				• **1)** Farm advisors. • **2)** Farm to farm information.		• **1)** Samples collection will be conducted by both of SPNA and Wageningen university. • **2)** Samples analysis and data analysis will be conducted mainly by Wageningen University.

Netherlands Kollumerwaard NBS Straw, grass clover, fresh grass aphids	**SPNA**	**SPNA**	• **1)** Farm advisors, businesses selling potatoes with less diseases due to the solution.	**Seed potato farms**	• **1)** Seed potato farmers and; • **2)** Stakeholders that communicate about the solution being found	• **1)** Farm advisors. • **2)** Farm to farm information.		**SPNA will be responsible**
Netherlands Kollumerwaard NBS Cover crop in a seed potato-based crop rotation	**SPNA/ WUR?**	**SPNA**	• **1)** Farm advisors. • **2)** Company's selling cover crop mixes.	**Seed potato farms**	• **1)** Seed potato farmers and; • **2)** Stakeholders that communicate about the solution being found	• **1)** Farm advisors . • **2)** Farm to farm information.		**SPNA will be responsible**

Netherlands Ebelsheerd Pellets in Winter wheat	**SPNA**	**SPNA**	• **1)** Farm advisors. • **2)** company's selling pellets.	**Arable farmers**	**Arable farmers**	• **1)** Farm advisors. • **2)** Farm to farm information.		**SPNA will be responsible**
Netherlands Ebelsheerd Grass clover in organic wheat	**SPNA**	**SPNA**	• **1)** Businesses selling grass clover. • **2)** Farm advisors.	**Arable farmers**	**Arable farmers**	• **1)** Farm advisors. • **2)** Farm to farm information.		**SPNA will be responsible**

3.3 The NBS Sites in United Kingdom

The NBS sites in the United Kingdom will be at Rothamsted Research's main research farm in Harpenden, Hertfordshire (north of London), a site in the east of England (Brooms Barn in Suffolk) and at the North Wyke research farm in Okehampton, Devon (southwest England).

Rothamsted is also home to the 'Classical Long-Term Experiments', the world's longest-running agricultural field experiments. The main NBS to be tested in the UK involve diversifying arable rotations and using bio-based fertilisers, in particular:

i) Crop rotations and use of cover crops and green manure (the Large-Scale Rotation Experiments (LSRE) at Harpenden and Suffolk);
ii) Recycled fertiliser made from abattoir by-products (primarily bones) as a source of phosphorus.
iii) Farmyard manure (P) applications efficiency by (a) testing the mobile phone application "Farm Crap App" with farmers to calculate the quantities of nutrients they applied in manure, and (b) investigating the efficiency of farmyard manure application in combination with other mineral fertilisers to find the optimum amount.

We will collect and interrogate data on productivity, nutrient use efficiency and environmental health from the LSRE (started in 2018 at Harpenden and 2017 in Suffolk) across three contrasting rotations that differ in the number and identity of crops grown and duration of rotation (3, 5 and 7 years); all phases of each rotation are represented every year.

Within the experiment there is also the option to investigate the impacts of organic (manure) vs. mineral fertilisers and ploughing vs. minimum tillage.

Other experiments established over 170 years ago will provide data that informs us on the impacts of long-term organic amendments compared to mineral fertiliser applications. Key variables that will be measured are crop yield and quality, nutrient budgets, N and P availability in soils, soil organic carbon, soil structure and aggregate stability.

At Rothamsted's North Wyke site in Devon, we will work with a company called Elemental Ltd that have developed a method for processing abattoir and other livestock production systems by-products to optimise food products and also to produce a phosphorus and carbon rich bio-fertiliser derived primarily from animal bones, resulting in a fully circular recovery process with zero waste.

The efficacy of the fertiliser is being investigated using experimental and demonstration field plot trials comparing the efficiency of this fertiliser with conventional mineral fertilisers and traditional organic amendments (e.g. farmyard manure).

The early farmer workshops will identify which aspects of the NBS demonstrations we are testing are of greatest interest and seek to establish a new network of farmers who will test them on their own farms.

In tables 12-15 we present an NBS inventory for the UK sites with key information on challenges addressed, the plan for implementation, etc. This information is taken from the surveys each NBS partner filled out.

TABLE 12. SUMMARIZING NBS, THE CHALLENGES ADDRESSED, AND THE SYNERGIES OBTAINED IN THE UK

Country and NBS	Challenge(s) addressed with NBS	Synergies beside directly addressed challenges
United Kingdom		
Rothamsted Research, Large-Scale Rotation experiment (LSRE) Rotation (increased proportion of legumes), use of green compost from household garden waste as an organic fertiliser, cover crops, reduced tillage, integrated pest management (non-chemical options including companion cropping, resistant cultivars and delayed drilling)	Not designed to address a specific challenge but designed to study trade-offs between agronomic, environmental and economic outcomes. Has been used to inform integrated weed management, improved nutrient use efficiency and provide data for achieving net-zero.	We anticipate that systems that combine NBS will have more diverse, less competitive weed communities, better soil health (combination of structure and biology) leading to better water regulation and more diverse communities of natural enemies of crop pests.
Rothamsted North Wyke Novel biobased fertilizers on crop and grass & clover ley production. Arable and grassland fertilization with recycled organic material from animal production system (manures and animal by-products from abattoir).	Viability of use of alternative fertilizers to standard bagged dry fertilizers in order to produce crops.	Possible examination via life cycle assessment for nutrient inputs and outputs from the various nutrient applications.

TABLE 13. SERIES OF QUESTIONS RELATED TO THE TYPE OF NBS AND CHALLENGES ADDRESSED.

Your site/NBS description	Which NBS do you work with at your site?	Which challenge(s) do you address within the NBS site?	By the end of the project which specific measurement(s) or outcomes will determine your success in addressing this/these challenge(s)	By applying your NBS which bio-geo-physical synergies are likely to be obtained besides the challenge(s) directly addressed?	Which synergies besides the challenge(s) directly addressed will you measure as part of this project	What other NBS could potentially be relevant for your NBS site addressing the same challenge?
Rothamsted Research, Large-Scale rotation experiment	• **1)** Crop Rotation. • **2)** Green compost (organic fertiliser-Green Waste). • **3)** Cover Crops. • **4)** Reduced Tillage. • **5)** Integrated Pest Management {IPM} (non-chemical, companion cropping, resistant cultivars, delayed drilling)	• **1)** Not designed to address a specific challenge but designed to study trade-offs between agronomic, environmental and economic outcomes. • **2)** Outcome envisioned: **2.1)** Inform integrated weed management. **2.2)** Improved nutrient use efficiency. **2.3)** Provide data for achieving net-zero.	• **1)** Quantify the contribution that NBS has to reducing the reliance on synthetic nitrogen fertilisers to maintain productivity.	**We anticipate that systems that combine NBS will have more diverse outcomes:** • **1)** less competitive weed communities. • **2)** Better soil health (combination of structure and biology). • **3)** Leading to better water regulation. • **4)** More diverse communities of natural enemies of crop pests.	**Maybe not directly funded by Trans4num but all outcomes listed in E13 will be measured over the lifetime of the project.**	**Alternative sources of nitrogen:** • **1)** Under sowing cereals with clover. • **2)** Integration of livestock.
Rothamsted North Wyke, Devon, U.K.	Novel biobased fertilizers on crop and grass & clover ley production.	Viability of use of alternative fertilizers to standard bagged dry fertilizers in order to produce crops.	Yield and quality of arable crops and grass & clover.	Increased recycling of nutrients within the food production system, and less reliance on importation of newly produced macro fertilizers.	Possible examination via life cycle assessment for nutrient inputs and outputs from the various nutrient applications.	Depending on how many years the plot work is carried out for, but crop rotations could be incorporated for addressing the build-up of crop pests.

TABLE 14. SERIES OF QUESTIONS RELATED TO THE SCALE OF INTERVENTION, INTERVENING ACTIVITY, DATA MEASUREMENT AND MEASUREMENT PLAN.

Your site/NBS description	At which geographical scale(s) do you work with your NBS (e.g. farm, catchment, local, regional scale)	What is the size of your NBS site? (ha, km2)	Please list data collection periods planned for, including time and time span for each data collection
Rothamsted Research, Large-Scale Rotation Experiment (LSRE)	**Field scale - large plots (24 x 24m)**	**9 ha at two sites**	**While not funded by Trans4num, we will take the following annual measurements:** • **1)** Yield + nutrient content of offtake, soil microbiology, worms, carabid beetles (pitfall trapping). • **2)** In addition, the following measurements are taken every three years so one recording period will fall within the project lifetime: weed seedbank, soil physical and chemical properties to 1m depth (including bulk density and soil carbon). • **3)** Additional historical data is also available for this NBS site.

Rothamsted Research North Wyke, Devon, U.K.	**NBS experimental demonstration site involves plots at sub-field scale, but the application of fertilizer being tested works at all levels from plot, to farm, to catchment, to region and to nation.**	**1 ha**	Crop production - as determined by crop growth, arable crops once per year, grass & clover up to three times per year. Annual assessment of crop production and quality. Soil assessment carried out yearly, with emphasis on initial soil chemical nutrient contents and post crop harvesting contents, with particular interest in soil carbon.

TABLE 15. SERIES OF QUESTIONS RELATED TO IMPLEMENTATION AND MAINTAINING OF THE NBS - GOVERNANCE ARRANGEMENTS.

Your site/NBS description	**Which stakeholders/ who will you directly involve in collection of the bio-geo-physical data?**	**Who will be directly responsible for implementing NBS at your particular NBS-site**	**Who will be needed to support the implementation of NBS at your particular NBS site**	**Where do you consider your NBS relevant to be implemented outside your particular NBS site?**	Who will be directly responsible for implementing NBS in relevant areas outside your particular NBS site	Who will be needed to support the implementation of NBS in relevant areas outside your NBS site	Implementing institutions (formal or informal legal governmental structures and/or organizations that will affect/influence implementation	**Responsible for data collection?**
Rothamsted Research, Large-Scale Rotation Experiment (LSRE)	**Data collection will be done in-house with no stakeholder involvement.**	**Currently managed by a group of individuals at Rothamsted but exploring ways of expanding the group to include external stakeholders.**	**The scientists and farm teams located at Rothamsted.**	**The management factors included on the LSRE are relevant to any cereal based cropping system in the UK.**	• **1)** The LSRE will be mainly used to engage farmers and advisors in conversations around NBS to encourage uptake. • **2) It will be** used as a demonstration site for supply chain stakeholders including Unilever and Nestle.	• **1)** The LSRE will be mainly used to engage farmers and advisors in conversations around NBS to encourage uptake. • **2)** It will be used as a demonstration site for supply chain stakeholders including Unilever and Nestle.	• **1)** Primarily national government through public subsidy schemes. • **2)** Increasingly also incentives from buyers of produce (Consumers). • **3)** Access to natural capital markets (green finance).	Rothamsted scientists

Rothamsted North Wyke, Devon, U.K.	**Data collection will be done in-house with no stakeholder involvement, although the company producing the fertilizer (Elemental Ltd) will be closely involved in all aspects of the project and provide some chemical analyses. .**	**Currently managed by a group of individuals at Rothamsted but exploring ways of expanding the group to include external stakeholders.**	**Just the scientists and farm teams located at Rothamsted.**	**That might depend on the results of the trial, but, if it produces positive results, the NBS could be applied at all areas with arable or improved pasture livestock production**	• 1). • 2) Farmers or contractors will be responsible for using the fertilizer on agricultural land.	If the people want to uptake it as a result of the trial, then farm advisors will be key (e.g. catchment sensitive farming team or agronomists) The industry partner, Elemental Ltd., will be responsible for distribution of the fertilizer trialed in this project	Private companies are those that would implement, but it could be supported by farm advice delivered by the government (e.g. Defra)	Rothamsted scientists

3.4 The NBS site in Hungary

Szigetköz region, rich with flora and fauna, plays an important role in preserving biodiversity and has a high potential for buffering nitrogen, phosphorus and toxic heavy metals. Still, the intensive crop production system practiced in the region coupled with extreme weather conditions constantly challenges yield productivity and soil quality.

Specifically, decline in soil organic matter content has reduced the soil fertility which then negatively affects the production quality and yield. Innovative NBS are needed to maintain and improve the soil fertility status, enhance resilience of agricultural production, reduce environmental mineral chemical exposure and chemicals in crops, and combat adverse effects of climate change and water scarcity in Szigetköz region. Therefore, trans4num proposes to test and study the following NBS innovations:

• Crop rotation with diversity of crops (e.g., durum wheat, sorghum, soya) and mulching;

• Bio-based fertilizers applying pelleted chicken manure as a non-chemical fertiliser;

• Biostimulants applying microorganisms to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits. trans4num will conduct experimentations in three replications comparing the NBS innovations with conventional intensive farming systems. The trials will be conducted on a 25-ha land with three years' rotation: durum wheat, sorghum and soya. Trans4num will conduct the experimentation together with practice partners and local stakeholders on the Kimle and Mecsér experimentation sites. Soil quality after application will be tested using fast sensor-based technology to examine the effect of the NBS introduced on soil structure and organic matter improvement as well as yield improvement.

In the Hungarian site, a number of NBS innovations will be tested and demonstrated.

In table 16-19. A NBS inventory with key information on challenges addressed, the plan for implementation, etc. This information is taken from the surveys each NBS partner filled out.

TABLE 16. SUMMARIZING NBS, THE CHALLENGES ADDRESSED, AND THE SYNERGIES OBTAINED IN HUNGARY.

Country and NBS	**Challenge(s) addressed with NBS**	**Synergies beside directly addressed challenges**
Hungary		
Crop rotation (durum wheat, sorghum, soya)	Practice of planting different crops sequentially on the same plot of land to improve soil health, optimize nutrients in the soil, and combat pest and weed pressure.	All in all, we expect to obtain increased carbon sequestration in agricultural soil, improved soil biological activity, better soil structure, increased organic matter, we expect increased number and the number of species of insects and pollinators communities and due to this increased number and species of birds. We expect lower carbon emission. It is expected to show the path towards t a more sustainable production methodology.
No tillage	No tillage reduces carbon emission and increase carbon content in soil.	
No herbicides, minimalized pesticides	No herbicides, minimalized pesticides use will increase the biological activity an C cycling in soil.	
Biobased fertilizers (poultry manure pellet)	Using natural fertilizer instead of artificial	
Biostimulant	Using natural fertilizer instead of artificial. Biostimulants improve measurable crop productivity under environmental stress. Biostimulants improve measurable crop productivity under environmental stress.	
Cover crops after wheat over winter (mulching)	Cover crops offer a natural and inexpensive solution through their ability to capture atmospheric CO_2 into soils. Cover crops also help make the soil healthier and make the crops more resilient to climate change.	

TABLE 17. SERIES OF QUESTIONS RELATED TO THE TYPE OF NBS AND CHALLENGES ADDRESSED.

Your site/NbS description	Which NBS do you work with at your site?	Which challenge(s) do you address within the NBS site?	By the end of the project which specific measurement(s) or outcomes will determine your success in addressing this/these challenge(s)	By applying your NBS which bio-geo-physical synergies are likely to be obtained besides the challenge(s) directly addressed?	Which synergies besides the challenge(s) directly addressed will you measure as part of this project	What other NBS could potentially be relevant for your NBS site addressing the same challenge?
Hungarian NBS intervention example	• **1)** Increased Crop Rotation. • **2)** No tillage. • **3)** No herbicides or Minimalized pesticides use. • **4)** Using natural fertilizer instead of artificial. • **5)** Using natural fertilizer (Bio stimulant) instead of artificial. • **6)** Cover crops. • **7)** Crop and soil Monitoring.	• **1)** Soil Health/NUE/Combat pests & Weeds. • **2)** Reduce CO2 emissions / C-sequestration. • **3)** Increase biological soil activity / C-cycling. • **4)** Using natural fertilizer (Poultry manure). • **5)** Increase crop productivity under environmental stress & Climate change. • **6)** Mulching wheat over winter C-sequestration & resilience for climate change. • **7)** Manage multiple fields / Cut costs / Data based discissions tool for improved outcomes.	• **1)** Crop rotation practices can result in increased carbon content in soil that can be measured with soil total carbon and humus measurements. • **2)** The increase of Humus and total carbon content can be measure in soil. CO2 emission from soil will be also measured. • **3)** Different carbon content and biological activity of soil can be measured. • **4)** Increased N and carbon content of the soil can be measured. • **5)** healthier crop and increased measurable yield. • **6)** Increased carbon content is measurable parameter in soil. • 7) Crop and soil monitoring systems help to reduce the risks and resilience of climate change. Measures: Organic carbon content in soil. pH, Organic Matter, N Total, P (M3), K (exch.), Ca (exch.), Mg (exch.), CEC, Al Total, Iron Total, Clay, Moisture, % Vegetation indexes.	• **1)** Increased carbon sequestration in agricultural soil. • **2)** improved soil biological activity. • **3)** better soil structure. • **4)** increased organic matter. • **5)** Increased number of species of insects and pollinators communities and increased species of birds. • **6)** We expect lower carbon emission. • **7)** It is expected to show the path towards a more sustainable production methodology.	**The experiences of the local farmers about the current practices will be used**	**We use more NBS, so most of the NBS solutions are included at the NBS site**

TABLE 18. SERIES OF QUESTIONS RELATED TO THE SCALE OF INTERVENTION, INTERVENING ACTIVITY, DATA MEASUREMENT AND MEASUREMENT PLAN

Your site/NbS description	At which geographical scale(s) do you work with your NBS (e.g. farm, catchment, local, regional scale)	What is the size of your NBS site? (ha, km2)	Please list data collection periods planned for, including time and time span for each data collection
Hungarian NbS intervention example	**These NBS solution fits with:** • **1)** Farm • **2)** Catchment, local, regional scale. It is implemented on a representative field of the region. I will affect neighbouring fields, farms and landscapes.	**24 ha**	**Analyses will be taken according to phonological phase of soya, durum wheat, and sorghum 3 times per growing season:** • **1)** Soil & Plant analysis. • **2)** Remote sensing measurements. • **3)** CO2 measurements. **At harvest:** • **4)** yield quantity and quality parameters will be measured & The soil profile measurements: • **4.1)** Structure. • **4.2)** Organic matter. • **4.3)** Water management properties - will be also investigated.

TABLE 19. SERIES OF QUESTIONS RELATED TO IMPLEMENTATION AND MAINTAINING OF THE NBS - GOVERNANCE ARRANGEMENTS.

Your site/NBS description	Which stakeholders/ who will you directly involve in collection of the bio-geo-physical data?	Who will be directly responsible for implementing NBS at your particular NBS-site	Who will be needed to support the implementation of NBS at your particular NBS site	Where do you consider your NBS relevant to be implemented outside your particular NBS site?	Who will be directly responsible for implementing NBS in relevant areas outside your particular NBS site	Who will be needed to support the implementation of NBS in relevant areas outside your NBS site	Implementing institutions (formal or informal legal governmental structures and/or organisations will affect/influence implementation	Responsible for data collection?
Hungarian NbS intervention example	• **1)** Farmer • **2)** researchers. • **3)** Advisors. • **4)** Integrators: Seed company & Bio stimulant company.	**Pannon-mag (as project partner, farmer, university researchers**	• **1)** Farmer • **2)** Researchers • **3)** Advisors • **4)** Integrators: Seed company & Bio stimulant company	**At all agricultural field in this Szigetköz region**	Farmers, see also column K	• **1)** Farmer • **2)** Researchers • **3)** Advisors • **4)** Integrators: Seed company & Bio stimulant company	**The national agricultural advisor service can be involved and AKIS network**	**Project partners: Széchenyi István University, Pannon-mag**

4. Exploring the Intersection of Interdisciplinary and Transdisciplinary Research on NBS

In the Trans4num project the focus is on exploring the intersection of how inter- and transdisciplinary research on NBS, this means systematically involving diverse knowledge holders (such as the Climate Foundations Skive, and farmers organisations etc,) in co-designing and implementing the project process. This approach has been recognized as a key factor for successful NBS implementation (e.g., Albert et al. 2020; Raymond et al. 2017; Calliari et al. 2019). To achieve this, inter- and transdisciplinary process should use various collaborative methods to engage and empower stakeholders (Faivre et al. 2017), this requires co-production and co-creation of knowledge (Short et al. 2019) from different sites (or even countries) through multiple sources across various scales.

4.1 Framing NBS for the inter- and transdisciplinary research

Interdisciplinary research is scientific research that relates to several disciplines and transgresses the broader fields of humanities and natural sciences (Knierim et al. 2010; Tress et al. 2007). Interdisciplinary includes an explicit analysis of underlying assumptions (perspectives, "worldviews") of each discipline, and an attempt to integrate discipline-specific knowledge. With an interdisciplinary approach, the 'facts' from each discipline are critically evaluated in light of the 'facts' from the other disciplines. Transdisciplinary research broadens the scope of research into another study dimension as besides the orientation towards real-life problems this approach also seeks to integrate lay or non-academic knowledge with scientific one (Knierim et al. 2018). Transdisciplinarity involves the collaboration of researchers from various fields and non-academic participants to generate new knowledge and address a shared problem (Tress et al. 2005).

As NBS's definition focuses on the co-evolving relationships of people and nature, it shall be framed as transformational and transdisciplinary. Transformation depicts fundamental, system-wide and 'scaling-deep' reorganization across technological, economic and social factors, including changing norms, relationships, cultural values and beliefs (IPBES, 2019; Moore et al., 2014 and 2015). Transformation is often mentioned alongside NBS to achieve resilient and sustainable development for people and nature (Woroniecki, 2020). Transformational framing may influence the four steps of processing NBS innovations: (i) problem recognition (i.e., characterising the local setting to identify the problem and address the challenge correctly), (ii) NBS identification (i.e., finding a potential NBS for a given site or context by identifying associated stakeholders, category, and performance criteria), (iii) NBS selection (choosing the best NBS by assessing impacts, feasibility, efficiency and effectiveness), and (iv) NBS upscaling (disseminating and symbolizing the NBS through stakeholder integration and cross-sector cooperation) (Gonzalez-Ollauri et al., 2022; Welden et al., 2021). Transdisciplinarity relates to a number of disciplines and transgresses the fields of humanities and natural sciences, in which boundaries between and beyond disciplines are transcended and knowledge and perspectives from the different fields as well as non-scientific sources are integrated (Bergmann et al., 2010; Knierim et al., 2010; Tress et al., 2007). Transdisciplinary framing can bring together previously researched disciplines, policies and action-focused practices, allowing for a common understanding of NBS, how it interfaces with the local and regional contexts, and what drives its effectiveness.

4.2 Systems Thinking of Agri-food Systems

Due to the complexity and transdisciplinarity, systems thinking may contribute to our inter- and transdisciplinary research (Arnold and Wade, 2015). We thus propose to focus on the agri-food system (AFS) which is a coupled system of agricultural production in fields and farms while being embedded in the social-ecological system between nature and human societies (Federal Ministry for Economic Cooperation and Development (BMZ), 2021; McGreevy et al., 2022). It is supported and influenced by the ecosystem and social system, and in turn, exerts feedback and spillover effects through the four key AFS components (Figure 6). **Resources** include human capital, natural capital, physical capital, financial capital, and political capital. They are utilized by multiple **actors**, such as farmers, consumers and traders, in the process of agricultural production and food storage, processing, disposal and consumption with regard to their needs and preferences. The resource use of multiple AFS actors may present a diverse and dynamic input and output flow, as the (re-) allocation of resources and (re-) distribution of benefits (e.g., yield and income) often vary across the different applications of knowledge and the various good practices in **technology** (e.g., set strategic objectives, take system inventory, and solution research). Such diverse and dynamic input and output flows may call for adaptive **governance** to facilitate appropriate AFS decision-making and enforcement addressing complex problems (e.g., disconnects between agriculture and ecosystem as well as between farmers and consumers), potential risks (e.g., pollution) and emerging challenges (e.g., climate change).

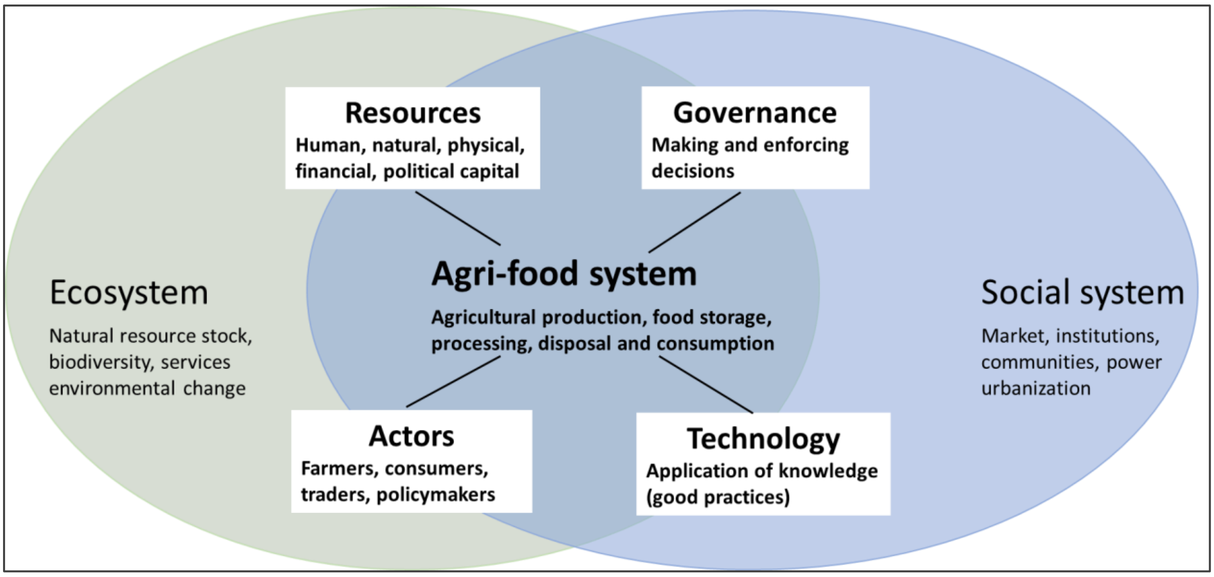

FIGURE 6. SYSTEMS THINKING OF THE AGRI-FOOD SYSTEM BETWEEN NATURE AND SOCIETIES.

By applying the AFS systems thinking, we may concretise the study lenses on the micro (e.g., farm or field), meso (e.g., landscape or watershed), and macro (e.g., national or international) levels. Therefore, we shall clarify what shall we discuss, what is needed, and how to do it.

What shall we discuss?

The AFS can be used to present one research object at a field or farm, landscape or watershed, and national or international levels. An explorative analysis is needed to scrutinize the biophysical, agronomic, and socio-economic contexts, map and identify the key actors and stakeholders and their needs, preference and capability, and assess the outcomes and impacts. Based on that, strategic objectives, desired outcomes and target goals shall be set up for the specific AFS study. It may help take a system inventory of the AFS and develop performance criteria clarifying good NBS practices for nutrient management in intensive farming. Also, it may help identify the capacity and/or capability and constraints in terms of the AFS resources, actors, governance and technology (Figure 6). Thus, parameters and indicators can be built to measure and test NBS innovations in relation to sustainable nutrient management. Furthermore, scenarios and pathways for transformative changes can be proposed and analysed with multiple stakeholder engagement with regard to the AFS trade-offs, leverage point, threshold and domain.

What is needed?

The abovementioned study could be conducted through a joint work of working packages, project partners or countries of project sites. In any case, we need to 1) align research questions with strategic objectives given the complex problems, potential risks and emerging challenges faced by the AFS, 2) take a system inventory of the AFS and select good practices for desired outcomes across the micro, meso, and macro scales, 3) monitor and clarify the AFS needs and constraints along environmental and socio-economic changes over time, and 4) Research and identify solutions to challenges related to nutrient management in intensive farming, such as nutrient overuse and deficit.

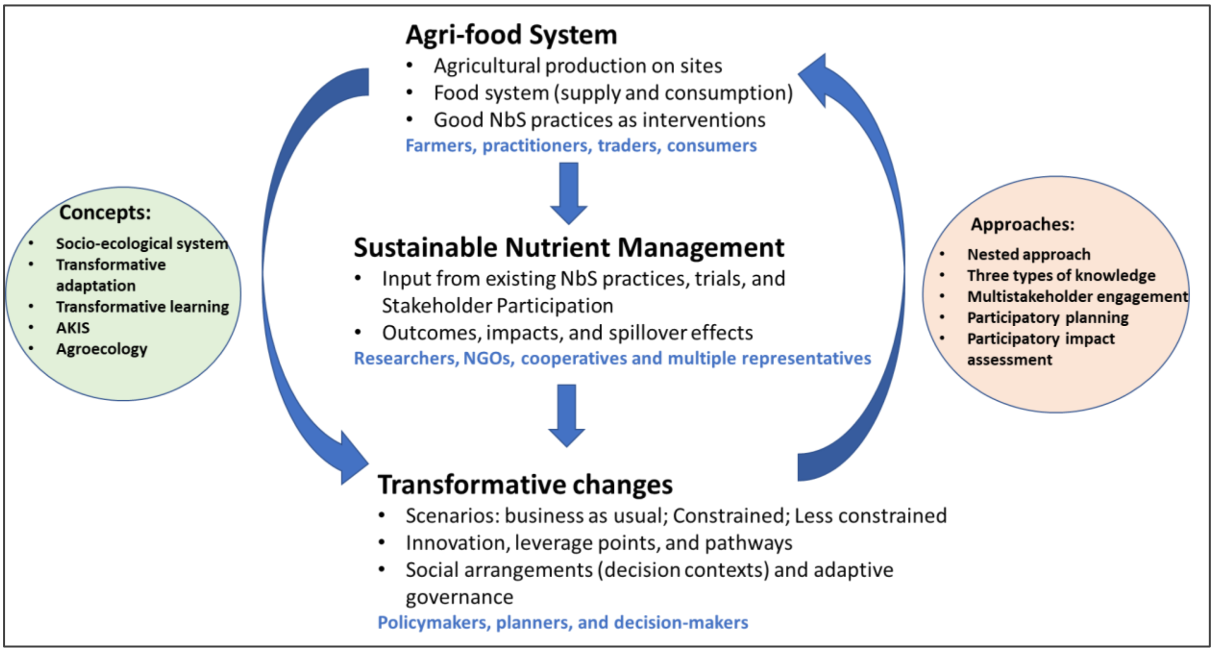

FIGURE 7. FRAMEWORK FOR SUSTAINABLE NUTRIENT MANAGEMENT AND TRANSFORMATIVE CHANGES IN AGRI-FOOD SYSTEMS.

How to do it?

By focusing on the AFS (Figure 6), we can probably integrate studies on agricultural production, food supply and consumption and interventions of good NBS practices into systematic research that interconnects multiple actors and stakeholders (e.g., farmers, practitioners and consumers) across farms, landscapes and value chains. It might include an explorative analysis of the AFS regarding the status of resources, actors, governance and technology as well as the interactions among them and with the ecosystem and societies, but also a normative analysis of good NBS practices in relation to nutrient management in intensive farming. These may support 'sustainable nutrient management' with input from the project sites, trials, satellite images, experiments, and stakeholder participation. By monitoring the nutrient flow along with changes in the AFS capability/capacity and constraints over time, optimum nutrient supply and associated environmental and socioeconomic outcomes and effects could be estimated. It can be validated and tested with key stakeholders like researchers, NGOs, cooperatives and community members. After that, scenarios of the AFS development with/without NBS application, like business as usual, constrained, and less constrained, can be designed to deliver transformative changes. Benchmarks and protocols of good NBS practices related to nutrient management in the AFS would be set up. Here, good NBS practices are considered leverage points to intervene in the complex system delivering transformative changes in the AFS identity, structure, and function. Social arrangements (i.e., decision-making and enforcing contexts) and adaptive governance for implementing good NBS practices in the AFS will provide insights on the transformation pathways towards sustainable nutrient management in intensive farming.

4.3 Concepts and approaches for the inter- and transdisciplinary research

Concepts like socio-ecological transformation, AKIS, agroecology, etc., and approaches such as nested approach and multi-stakeholder engagement, etc., may facilitate an integrative and coherent research.

Using the multi-actor approach supported by the AKIS concept

In trans4num, we use **the multi-actor approach** to consider various societal concerns and interests related to NBS in agricultural nutrient management and to identify needs and possibilities for social innovations conducive to a wider acceptance and adoption of NBS in agriculture. In doing so, we bring together experience, expertise and knowledge across different fields, technologies and disciplines from Europe and China and work in a collaborative manner that allows upscaling of complementary technological services for farmers. Here, the interface between practice and science is a key constituent which implies not only the necessity to create mutual understandings but to go far beyond towards interaction and collaboration among the various actors (Knierim et al. 2018). In trans4num, we will adapt and use tools and procedures of **interdisciplinary and transdisciplinary approaches** to facilitate transformative learning and change**.** The concepts will guide project partners to identify, describe and frame the NBS innovations in the selected sites; define a common objective, design conceptual and methodological frameworks to guide the knowledge integration, build a collaborative transdisciplinary team and conduct specific trials and dissemination of the main activities.

Three forms of knowledge to characterise the transdisciplinary research for sustainability

The transdisciplinary research for sustainability is characterised by three types of knowledge while addressing three kinds of research questions: system knowledge (what is), target knowledge (what should be), and transformation knowledge (how to get there) (Pohl and Hirsch Hadorn, 2007).

Systems knowledge**:** addresses questions about the genesis and possible further development of a problem (see problem), and about interpretations of the problem in the life-world (see life-world). Systems knowledge confronts the difficulty of how to deal with uncertainties (see uncertainties). These uncertainties are the result, on the one hand, of transferring abstract insights from a laboratory, a model or a theory to a concrete case underlying specific conditions. Furthermore, empirical or theoretical knowledge about a problem may be lacking, and depending on the interpretation of a problem, these uncertainties may be assigned different degrees of importance, which leads to diverging assessments of the need for action and of target knowledge and transformation knowledge (Pohl and Hirsch Hadorn, 2007).

Target knowledge**:** addresses questions related to determining and explaining the need for change, desired goals and better practices. In the case of target knowledge, the question is what the multiplicity of social goals means for research, for society's practice-related problems, and for transdisciplinary collaboration between science and actors in the lifeworld. Transdisciplinary research faces the challenge of clarifying a variety of positions and prioritising them in the research process according to their significance for developing knowledge and practices that promote what is perceived to be the common good. This is necessary not only when the need for action has to be identified and objectives have to be determined, but also when describing the systems to which they refer and the possibilities of inducing change (Pohl and Hirsch Hadorn, 2007).

Transformation knowledge: addresses questions about technical, social, legal, cultural and other possible means of acting that aim to transform existing practices and introduce desired ones. In the case of transformation knowledge (see transformation knowledge), established technologies, regulations, practices and power relations must be taken into account. This is the mere consequence of pragmatism, since options for change have to rely on existing infrastructure, on current laws, and to a certain degree on current power relations and cultural preferences, in order to have any chance at all of being effective. When these social, cultural and technological givens are not considered, this leads to the often-criticised discrepancy between knowledge and practice. For transdisciplinary research, the challenge here is to learn how to make what is established more 'flexible'. (Pohl and Hirsch Hadorn, 2007).

Multi-level perspective for system change/transformation: SET concept

Climate change, urbanization, digitalization, and increasing societal demands for land and land-based resources are driving and accompanying transitions in the European agricultural landscapes. The socio-technical transition model entails that transition to sustainability are challenging because they involve multiple actors in long-term, goal-oriented, disruptive, contested and non-linear interaction processes. Among other sustainability scholars, however, the socio-technical transition model has repeatedly been criticised for its technology focus, and a positivism driven approach towards societal change (Brand et al. 2020). Innovative nature-based solutions in agriculture, as e.g. ways to handle surplus nutrients in intensive livestock production, may thus turn out to be of incremental character only, and without the potential to contribute to sustainability in a comprehensive sense (Friedrich et al. 2021). In this respect, the social-ecological transformation (SET) concept has been proposed as a means of taking into account the situational contingency of change processes, the related uncertainties that actors may perceive, and of making society-nature relations a core concern of the design of change (Jahn et al. 2020).

Thus, understanding, analysis and assessment of the potential and impacts of NBS in a SET context require the development and implementation of a participatory stakeholder involvement process, which is tailored according to the features of the NBS under consideration in terms of scope and scale as well as with respect to governance institutions and regulative norms and policies. As such, cooperation has to be conducted as an open process, the design and the implementation of the participatory process will vary from one NBS site to the other. trans4num will develop a methodology for mapping, modelling and assessing the context in which NBS innovations occur, based on the Ostrom´s Socio-Ecological System framework (Ostrom, 2009), in which the Focal Action Situation (NBS innovations that will be tested) results from the interaction of Governance, Systems, Actors, Resource Units, and Resource systems. Corresponding to the multi-level conception of the social-ecological transformation (Fig. 2), trans4num will explore and assess NBS at three nested levels: a) field and farm, b) regions, watersheds, landscapes, c) food systems, value chains and innovation systems level (Fig. 3).

4.4 Inter- and Transdisciplinary work in the four NBS sites

In this section, we will describe in more details how are the different partners working with inter- and transdisciplinarity in the NBS sites, especially which data they are collecting, how and with whom. In summarizing the inputs from project partners, see table 19 below, besides this we will try to answer the following:

- How are the different partners working with inter- and transdisciplinarity in the NBS sites
    - How are we transgressing boundaries of scientific disciplines (inter-disciplinarity)
    - How are we transgressing research/practitioner boundary? (trans-disciplinarity)
- What are the site specific NBS indices and performance criteria used

Table 20: Summary of inter- and transdisciplinary work by each country

	Denmark	**Hungary**	**Netherlands**	**United Kingdom**
What do you as project partner understand with inter-disciplinarity and trans-disciplinarity?	Multiple academic disciplines collaborating on integrating knowledge methods and approaches and theories. They collaborate in order to generate innovative solutions and bridge knowledge gaps. When one discipline cannot deliver satisfactory answers. A more nuanced understanding is engendered as well as an understanding more relevant to real-world challenges. We need to be very aware of different epistemologies and how they may or may not integrate	In NBS solutions several branches of knowledge, and practices are involved	To be developed	Any research that involves more than one discipline working in close collaboration (e.g. social-ecological research, or combining soil research with plant science)
How do you work inter-disciplinary and trans-disciplinary at project level?	Integrates knowledge from both academic and non-academic disciplines. Is co-creative across levels and disciplines. Collaboration in both problem identification, research design data collection analysis and solutions/innovations developed. Has immediate practical relevance and action related/actionable knowledge. Does often require a systems perspective.	We integrate knowledge and methods from different disciplines, using a real synthesis of approaches. Transdisciplinary level we create a unity of intellectual frameworks beyond the disciplinary perspective.	To be developed	Regular meetings, shared goals and compatible methods. Usually with subject specific aims, but also key interdisciplinary aims too
How do you work inter-disciplinary and trans-disciplinary at NBS site level?	the identification of NBS biobased solutions is interdisciplinary in the sense that "grass" will solve more problems N leaching together with other issues such as carbon sequestration, biodiversity, etc. (the latter not necessarily measured). The systemic and action related research design is transdisciplinary involving both practitioners and researchers. Data collection will be both interdisciplinary (collection by and of both social and natural science /quantitative and qualitative data) However it will also be trans-disciplinary involving action research in order to generate solutions (symbiotic value chain/business symbiosis) to implement change. In	Several practices and experiences are involved	To be developed	Rothamsted regularly work across bio- and environmental science disciplines (e.g. combining soil science and crop science). We are now increasingly also working with social scientists

	transdisciplinary research a number of individuals and organizations will be involved: Farmers, investors, technology owners, regulators, advising, (cf. my slide forwarded to you individually).			
What kind of inter-disciplinary and/or transdisciplinary data will be collected in your site?	CF former tab. But be especially aware of the type of data related to readiness levels for transdisciplinary data	Both	To be developed	We are hoping to collect a mixture of natural science measures (e.g. soil carbon) and social science metrics (e.g. effort, costs)
What type of analytical approaches will be conducted in your NBS group?	Not sure how to answer this question. However, I think that one type of analytical approach is related to building the decision support tool and one type of analytical approach is related to engendering change. Different patterns and trends are identified. My slide is expressing a kind of analytical approach deconstructing elements of change that need to happen in order to implement innovative solutions. Modelling is an analytical approach in and by itself when applied to identifying patterns or trends and pointing towards possible evidence-based decisions.	To be developed	To be developed	A real mixture! It depends on the data and the RQ being asked

4.5 Inter- and transdisciplinary work in Denmark

In the Danish case an integrated approach is applied where landscape modelling based on agency inventory and standard regulatory agronomic data is combined with qualitative data collection through interviews with collaborating farmers at the NBS site and other stakeholders from the biomass chain. This approach thus integrates a wide range of knowledge at both the interdisciplinary and transdisciplinary level collecting knowledge from both different academic and non-academic disciplines.

The Danish NBS innovations are developed based on knowledge from multiple scientific disciplines to deal with societal challenges related to agriculture tackling both nutrient leaching, carbon emissions and biodiversity issues. Further, the data collection will include both agronomic data, satellite and weather data and socio-economic data thus involving different scientific fields in the project design, the data collection and the data analysis and dissemination. The broad systems perspective applied at regional level further allows for involvement of actors from the whole biomass chain including farmers, biorefineries and biogas plants as well as farm advisors and municipalities. This will ensure a broad transdisciplinary collaboration on both problem identification, research design, data collection and analysis, and development of solutions and innovations. The wide transdisciplinary involvement leads to immediate practical relevance and provides a good basis for conducting action research where stakeholders in the region are also gathered and mobilized to co-construct biomass exchange and supply systems to generate solutions and induce transformation. The different stakeholder groups will further be activated through direct responsibility of NBS implementation (farmers), upscaling (companies and organizations) and support (consultants and regulators). The collaboration across multiple disciplines with many stakeholders will make it possible to investigate different aspects of readiness levels regarding the NBS innovations including technological readiness levels, supply chain readiness levels, regulatory readiness levels and social/societal readiness level.

The performance of the NBS innovations will be evaluated on different criteria with indicators related to regulation targets, agronomic performance and socio-economic performance to assess if expected impact can be achieved and that the innovation will also be favourable to the involved stakeholders.

4.5.1 Data collection overview – Denmark

Denmark		
Agronomic data	Inventory standard data and farm reports to the agency: - Crop type - crop area - biomass produced - farm category and type - farm size - fertilizer and manure types and application including N content - exchange of biomass - animal units - number of animals - types of animals - housing systems Qualitative data from involved farmers/stakeholders: - Yield	- harvest time - cutting in seasons - local farm level data - fertilizer type and amount applied - application rate and date of fertilizer - actual N content of manures/fertilizers - local knowledge on housing systems (for nutrient content and emission calculation) - machinery (and shared machinery?) - technologies - diesel use - tillage data from FarmOnline Other - current and historical satellite land use data weather data?
Socioeconomic data	- Qualitative data on farmers' adoption of NBS including barriers and potentials for implementation. - Data on biomass exchange between farms, and between farms and biogas plants. - Soil value based in standard values Maybe include qualitative data on: - existing exchange systems - collaboration amongst farmers	- supply chains with grass for biogas production. - how much bio-based fertilizer and N the farmer receives back from the biogas facility. Technological readiness level, supply chain readiness level, regulatory readiness level and social/societal readiness level of green protein production.
Methods for collecting agronomic data	Standard values from inventory data and register data and reported values to the Agricultural agency.	Qualitative farm data from collaborating farmers that provide farm specific data through access to MarkOnline/FarmOnline and interviews.
Methods for collecting Socio-economic data	Interviews on farmers adoption of NBS, opportunities and barriers.	We are also doing action research with respect to gathering and mobilizing farmers on this agenda including co-construction of exchange systems supply systems and investments in a coming biorefinery plant?
Performance criteria	- Nitrogen reduction (kg N/ha) from root zone and to the recipient. Based on reporting and official register data. - Maybe GHG (including N2O) budgets to evaluate BBF. - Socio-economic performance (how?)	- NUE parameters Modelled flows
Involved Stakeholders and partners	- Farmers - Satellite and weather data specialists, - agronomists/agronomic advisors	- Stakeholders from the biomass chain. E.g., biogass plants and biorefinery - Municipalities

4.6 Inter- and transdisciplinary work in Hungary

The Hungarian NBS case is taking an approach involving both inter- and transdisciplinary scientific work and collaboration with multiple stakeholders including farmers, advisors and companies, thereby transgressing the boundaries of multiple disciplines and professions. The experiments will be conducted together with practice partners and local stakeholders. At the Hungarian NBS site natural and social science measures will be collected including performance indicators primarily related to yield, soil structure and soil organic matter but will also integrate economy, management and labour measures. The Hungarian approach further includes collection of qualitative socioeconomic data through interviews with farmers and advisors, which will provide information on the general knowledge about and interest in NBS adaption in their region. This will be of great interest since the farmers are identified as being the main responsible for upscaling the NBS innovation outside the experimental NBS site supported by advisors and companies. The performance of the NBS innovation will be evaluated based on nutrient, soil carbon, soil health and biodiversity measures which includes monitoring of soil N, P and C pools, soil chemical and physical properties, and earthworms and farmland birds.

4.6.1 Data collection overview - Hungary

Hungary		
Agronomic data	- Soil - plant analysis - remote sensing measurements - Yield quantity and quality - Soil profile - Structure - organic matter (in lab and with NIR sensor) - CO_2 emissions - water management properties - fertilizer and manure types and applied amounts (including N content) - machinery type and technologies - tillage and other field operations - weather data - satellite and drone data - Farm category, type and size	Measured soil parameters with NIR sensor: - pH - Organic Matter - N Total - P (M3) - K (exch.) - Ca (exch.) - Mg (exch.) - Cation exchange capacity - Al Total - Iron Total - Clay content - Moisture - CO_2 from soil
Socioeconomic data	Qualitative data: - General knowledge and interest in the region. - Knowledge on NBS adoption	Economic data: - Input cost vs yield
Methods for collecting agronomic data	- Measurements from conducted experiments. - Collecting data/knowledge from involved stakeholders	AKIS data and advisory system data
Methods for collecting Socio-economic data	- Interviews with farmers and advisors about NBS adoption. - AKIS data and advisory system data	
Performance criteria	- Soil N and P pools will be monitored through soil analysis. - CO_2 emissions will be measured (but not GHG budgets) - Soil health: visual analysis, earthworms	- Ecosystem/biodiversity: bird monitoring - Change in soil physics and chemistry. Soil plant analysis results will be compared
Involved stakeholders and partners	- Farmer - Researchers - Advisors	- integrators, seed company, biostimulant company

4.7 Inter- and transdisciplinary work in The Netherlands

Interests from local farmers in adopting NBS innovations to respond to the negative impact of agricultural production is the basis of the Dutch case. NBS innovations will be implemented at two experimental farms involving local farmer groups in designing and testing the innovations and in disseminating the results. This ensures direct relevance and applicability to farmers which is important for upscaling the NBS. Various types of measures related to crop growth and nutrient efficiency are collected to evaluate the impact of NBS innovations on environmental and agronomic performance. Also costs and work hours related to the NBS innovations are monitored including several socio-economic measures. This approach thus involves both inter- and transdisciplinary work across different scientific disciplines and the farming community. The performance of the NBS innovations will be evaluated on various environmental criteria using indicators as N and P leaching, N and P use efficiency, GHG emissions, physical soil structure, soil organic carbon and soil biodiversity, and also the agronomic performance will be assessed on yield and crop counting.

4.7.1 Data collection overview – The Netherlands

Netherlands		
Agronomic data	- crop type - crop rotation - crop area - harvest time - biomass produced - yields - N/P content in crops - N/P uptake - cuting in growing season - Fetilizer source - Fertilizer applied amount - application method - time - N/P content in the applied fertilziers - amount of aphids on sticky plates - soil samples - aggregate stability	- soil organic carbon - soil nutrients (N and P) - soil biodiversity (earthworms, AMF, microbial diversity) - crop samples - machinery used - working hours - farm category, type and size. - GHG emissions - Information about cover crop and nutrient effects in the soil after destroying the cover crop. - Information about the growth of Winter wheat/organic wheat, global health conditions and potential diseases. - Nutritional value of fertilizer pellets Nutritional value of grass clover
Socioeconomic data	- Cost of input material and contractor machinery - Work hours/tractor hours	
Methods for collecting agronomic data	- Measurements and inventory data from previous years	
Methods for collecting Socio-economic data	- Measurements of workhours and economical costs	
Performance criteria	- Reduction of N and P leaching from root zone - GHG emissions - Nitrogen emissions - Nitrogen use efficiency (NUE) - Phosphorus use efficiency (PUR) - Global health conditions - Crop counting	Soil health: - soil structural stability (aggregates) - soil carbon cycling (SOC) - soil nutrient cycling (total and available nitrogen and phosphorus) general soil biodiversity (earthworm, AMF and microbial diversity))
Involved stakeholders and partners	- farmers - researchers	

4.8 United Kingdom

At the UK NBS sites different scientific disciplines are collaborating at the inter- and transdisciplinary levels to study trade-offs between agronomic, environmental and economic outcomes under NBS implementation. The project includes regular work across biological and environmental science disciplines when investigating cropping systems e.g., combining soil science and crop science in a holistic approach. At the NBS site natural science measures related to the cropping system and social science metrics related to costs will be collected, and it will be investigated if it is possible to collect other social science metrics such as effort associated with the NBS innovations. Further, to widen the scope and the relevance of the NBS innovations the possibilities of expanding the project to include external stakeholders will be explored. This will be carried out by establishing demonstration field trials and inviting farmers to farmer workshops to establish a new network of interested farmers who agree to implement the NBS at their own farms.

The performance of the NBS innovations will be evaluated with agronomical indicators such as nitrogen and phosphorus use efficiency and reductions based on inputs and off takes from the site, GHG emissions, soil bulk density and soil carbon. Further the NBS innovation will be assessed on criteria related to farm and soil biodiversity with worms, natural enemies and soil microbiology as indicators. From a socio-economic perspective the NBS innovation will be evaluated on input costs and returns related to the innovation itself and maybe estimates on work hours.

4.8.1 Data collection overview - UK

UK		
Agronomic data	- crops - crop area - crop rotation - harvest time - biomass produced - yields - components of yields (harvest index) - nutrient content of grain or biomass - cuttings in growing season - nutrient uptake	- compost nutrient content - fertiliser input (organic and synthetic) - soil type - field management: field operations and machinery type - weather data - farm type and categories from conventional to regenerative - - GHG measurements in selected plots
Socioeconomic data	- Estimated input costs - Maybe a possibility to estimate workload (hours for 1 ha crop/year)	
Methods for collecting agronomic data	- Measurements	
Methods for collecting Socio-economic data	- Measurements of workhours and economic costs	
Performance criteria	- Nitrogen and phosphorus reduction (based on inputs) - NUE and PUE based on inputs and off take (i.e. empirical equations, not simulation models) - GHG loss in some plots - Input costs and returns - Worms and natural enemies	Monitoring soil health: - bulk density - soil carbon - nutrients soil microbiology
Involved stakeholders and partners	- Exploring ways of expanding to include external stakeholders	

5. Conclusions and next steps

In the trans4num consortium, a diverse group of researchers and practitioners jointly work towards developing and promoting the NBS approach for sustainable agricultural practices in Europe and China with a particular focus on nutrient management. In Task 1.2 and with this deliverable 1.3 reporting, joint understandings of the approaches for the interdisciplinary analyses of NBS across sites and scales have been developed. A series of webinars showed a range of approaches towards and practices of NBS in the four NBS sites in the Trans4num project, the webinars also helped inform and lay the grounds for a better understanding of how each partner is working.

This report is compiled to comprise all the different NBS sites and collaborations. The objective is to facilitate learning, adaptation and cooperation between the different partners involved. Engaging in knowledge exchange on the why, and how is important for learning and producing relative outcomes. Comparisons can be drawn from the different NBS sites based on why set NBS concepts are utilized as each stakeholder has their own unique obstacles and challenges to overcome. Conceptual engagement between all participants allows for in depth evaluation of the research methods and objectives pertaining to set chosen NBS. NBS has been illustrated hard to fully encapsulate in one definition, thus further advocating the need for engagement from multiple disciplines to improve our understanding of what should be encompassed by an NBS. The summaries given in this report focusses on how each site is approaching it's NBS, these solutions are geared towards solving real world challenges. Challenges addressed will only be successful with stakeholder engagement, as adaptation of set results would need engagement from farmer, industry, consumer, and governmental agencies as a whole. As NBS are focused on the socio-ecological benefits and how these can interrelate to produce a more sustainable society inter- and transdisciplinary cooperation between partners can assist in improving outcomes of research undertaken. The focus point for this task is the potential for inter- and transdisciplinary engagement between the four NBS sites. Interestingly these nested concepts for NBS have different utilization outcomes as illustrated in the summaries pertaining to each NBS site. The general theme that connects all sites is the improved nutrient use efficiency that is nested in a biologically/natural obtained fertilizer or practice. These concepts of biological and natural would naturally have many nuances however, these should be used considered in the NBS framework that is nested in a socio-ecological directive. When comparison is drawn between analysis and outcomes planned NBS site partners have different measurement criteria for the analysis of success obtained. All four sites have plans for how the NBS innovations will be tested and demonstrated. A NBS inventory with key information on challenges addressed, the plan for implementation, the scale of intervention, intervening activity, data measurement and measurement plan, implementation and maintaining of the NBS- governance arrangements.

Three main criteria are evident from all site partners and measurements chosen to evaluate project outcomes. The three main nested concepts between site partners are stakeholder uptake, environmental improvement, and improvement of farming related inputs (Nutrient input). These three criteria have different measurements associated with them, but the outcomes have stayed true to the NBS mantra of socio- ecological improvement in the agricultural industry. As summarized in the survey site partners have elucidated the importance of multiple tiers of engagement needed from farm level, industry, consumer, and governmental agencies for successful implementation of these NBS. Technological and economic output are not used as a main driver for adoption, and this is an important point to stress as stakeholder engagement is crucial for these NBS to work. As in the case with all partner sites and the NBS proposed a clear uniform directive in the objectives is shown which aims to improve agricultural practices via sustainable practices and inputs adapted from nature.

On each of the NBS sites (in Denmark, Hungary, The Netherlands and in UK) the partners responsible for NBS sites have selected, have begun to test and are studying NBS innovations with a system approach thereby allowing to define, monitor, and assess the effects at field/local, farm, landscape, and regional level - embracing them as a nested, multi-level social-ecological system in transformation.

For the coming years, agronomic field-level trials are used, in some sites, to generate data for the monitoring and assessment of nutrient management, whereas real life farm data are used in other sites. Workshops, demonstration events, field days and excursions will be used to obtain practice users' appraisals and socio-economic data on NBS. The connection and collaboration between real-world challenges and data gathering with research will be crucial for outcomes beneficial for transforming the nutrient management regime.

Academic NBS sites coordinators and farm managers, farmers organisations and related stakeholders will work in close cooperation guided by a mix of applied natural and social sciences methods and elements of networking and facilitation.

Next steps

All insights from the NBS sites' activities will be documented in yearly reports (D2.2-D2.8). Additionally, for one or several selected NBS cases per site, an AKIS analysis will be conducted with empirical social research (D2.9). All results will have stand-alone character per site and feed into dissemination activities, but equally be part of the qualitative comparative assessment of NBS innovation processes across sites (D4.4).

All partners are to apply the nested concept when describing NBS and to use the features derived from the three statements to characterise them further.

Partners to work on open points and share progress in this respect within the consortium, in their yearly reports.

Acknowledgment:

The authors are highly appreciated to the valuable contributions of Simon Willcock, Jonathan Storkey, Martin Blackwell, Steven Emery, Robert Dunn, András Vér, Krisztina Takács, Viktória Vona, István Mihály Kulmány, Yan Wang, Jeroen Wolters, Anne-Mette S. Langvad, Maria Alejandra Arias Escobar, Anton Rasmussen, Mette Vestergaard Odgaard, Maria Vesterdal, and Tommy Dalgaard.

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7. Appendix

Appendix 1.

Table A1. Updated Indicators for framing site-specific practices to NBS.

Agro-characteristics							Farm description		Socio-economic characteristics				Performance criteria				
Crop data, (crops, crop area, harvest time, biomass, yields, N content, cutting in growing season, nutrient uptake etc.)	Fertilizer data (type, application time, rate, etc.)	Soil type	Livestock data (livestock numbers, manure, etc.)	Machinery used (machinery type, technologies, etc.)	Management practices (tillage,	Other data	Farm type	Conventional/Organic	Qualitative data: Interviews (observations data, Surveys, Ethnography, etc.)	Organizational data (manure distribution networks, advisory system, etc.)	Economic data	Other data (workload, etc.)	Nitrogen reductions (kg/N/Ha, Tons N, etc.)	Phosphorous reductions (kg/P/Ha, Tons P, etc.)	Nutrient use efficiency (NUE approaches used or nitrogen balances)	Data collection methods for nutrients (nitrate leaching, N2O emissions, etc.)	Other data