Final research report

Identifying nature-based solutions (NBS) and green infrastructure (GI) for more resilient rural communities in Asia

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Abbreviations

ASEAN	Association of Southeast Asian Nations
CAP	Common Agriculture Policy
CBD	Convention on Biological Diversity
CFS	Committee on World Food Security
CSA	Climate-smart agriculture
EbA	Ecosystem-based adaptation
EbM	Ecosystem-based mitigation
EC	European Commission
EEA	European Environment Agency
EIB	European Investment Bank
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GAP	Good agricultural practice
GCA	Global Commission on Adaptation
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GI	Green Infrastructure
ICEM	International Centre for Environmental Management
ICIMOD	International Centre for Integrated Mountain Development
ICM	Integrated coastal zone management
IFAD	International Fund for Agricultural Development

ILM	Integrated Land Management
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KJWA	Koronivia Joint Work on Agriculture
MCA	Multi-criteria analysis
MEA	Millennium Ecosystem Assessment
NAMA	Nationally Appropriate Mitigation Action
NAP	National Adaptation Plan
NBS	Nature-based solutions
NCP	Nature's Contributions to People
NDC	Nationally Determined Contributions
PES	Payment for ecosystem services
REDD+	Reducing emissions from deforestation and forest degradation
RIAFS	Responsible Investment in Agriculture and Food Systems
SALT	Sloping Land Agriculture Technology
SDG	Sustainable Development Goals
SFM	Sustainable Forest Management
SLM	Sustainable land management
UN	The United Nations
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
WB	The World Bank Group

Foreword

By FAO

Executive summary

Food systems in Asia and the Pacific, and agricultural production systems in particular, are key drivers of and subject to multiple, interconnected risks including ecosystem degradation, pollution and climate change as well as persistent undernourishment and malnutrition. Solutions that address these risks in an integrated and sustainable way are urgently needed. However, interventions designed to resolve these problems in an agricultural context have tended to focus either on sustainable production practices or conservation and restoration of natural ecosystems. Evolving from the Millennium Ecosystem Assessment, nature-based solutions (NBS) have gained attention as practical options that promote development and investment compatible with environmental, economic and social sustainability. While NBS are increasingly applied in urban development and natural forest and wetland ecosystem management, the concept of NBS and NBS options are underutilized in agricultural production systems.

This report documents the development of a framework on NBS specifically for agriculture. For the purpose of this report NBS in an agriculture context is defined as "the use of natural processes or elements to, over various temporal and spatial scales, improve ecosystem functions of environments and landscapes affected by agricultural practices, and enhance livelihoods and other social and cultural functions". The report presents analysis and a technical framework drawing upon a literature review of 188 scientific publications and a regional expert consultation, to classify and apply NBS in the agriculture sector. In an applied context, this framework can be used as part of a multi-disciplinary approach to gradually add functionality and purpose to agricultural production landscapes, (typically) starting with production-focused sustainable practices, and then moving on to green infrastructure and amelioration practices as well as conservation or restoration. Specifically, the four core solution types under framework are:

(1) Sustainable practices – primarily for production purposes, including natural nutrient and microclimate management, e.g. agroforestry and windshields. Benefits to people include more diverse and/or higher production quality, more stable productivity, safeguarded livelihoods, and reduced damage by frost or heat.

(2) Green infrastructure - primarily for engineering purposes, including physical regulation of water and soil, and slope stabilization, e.g. grass strips, hedgerows, or terraces using natural material. Benefits to people include reduced damage by mass movement, protection against storm surges and floods, reduced erosion, and additional fodder.

(3) Amelioration – primarily for restoration of conditions for plants, water, soil or air and climate change mitigation, e.g. bio- and phytoremediation and mangroves. Benefits to people include safe water, reduced health impacts stemming from production, pollinators, natural predators, biological pest control, and carbon sequestration.

(4) Conservation – primarily for maintenance or increase of ecological health at field or landscape scales, e.g. natural fallow or regeneration. Benefits to people include general well-being, safeguarded

biodiversity, supported nutrient cycles, fish and raw materials, cultural and spiritual benefits, and increased resilience to environmental stress.

Application of the framework requires additional consideration of scale and time; particularly how to best spatially and temporally (i) select and sequence what and how to intervene to generate positive biophysical interactions and social benefits in and between agroecosystems, and (ii) sustainably expand connectivity of positive interactions. These additional elements of NBS in an agriculture context presume an inclusive process where diverse stakeholders are consulted in the development of solutions. NBS is an inclusive and people-centred approach that aims to enhance ecosystem functions for the benefit of people and the environment.

It is important to acknowledge that the elements that make up the NBS framework for agriculture are not new. Each element of the framework builds upon a variety of concepts that address traditional challenges in agriculture, related to sustainable production and conservation. This report presents a first attempt at developing a normative framework for NBS in agriculture that brings together the conventional divide between production and conservation by bridging approaches to enhance agricultural production systems while maximizing opportunities to restore natural and agroecosystems. The framework is underpinned by a problem-based logic that support the development practical measures that are likely best targeted at landscape scale and/or sub-national levels. Complimentary practices and approaches, including local and indigenous practices, have been mapped to the framework and promising models are presented for analyzing and applying different solutions. The analysis presented in this report indicates that that the application of NBS approaches in agriculture to date have been small in scale and focused on marginal lands at the fringes of major production landscapes. To realize the full potential of NBS, efforts to apply the framework in major production landscapes that are the drivers of more significant agroecosystem degradation would be instructive.

Specific recommended next steps for NBS in agriculture include i) testing the applicability of the framework in key production landscapes; ii) developing and applying diagnostic assessment and monitoring tools specifically for NBS in agriculture, iii) setting up multidisciplinary NBS networks at different levels; and iv) efforts to link the adoption of NBS approaches in agriculture to existing policy process such as the SDGs as wells as global processes on NBS such as IUCN's NBS standards and the NBS Initiative .

Key messages

- NBS in agriculture use natural processes or elements to, over various temporal and spatial scales, improve ecosystem functions of environments and landscapes affected by agricultural practices, and enhance livelihoods and other social and cultural functions
- NBS can offer multiple designs/solutions to address some of the most pressing problems faced in Asian agricultural landscapes
- NBS for agriculture integrate sustainable practices, green infrastructure, amelioration and conservation
- Application of NBS in agriculture require consideration of the scale and time over which solutions are expected to be deployed and their relationship to local communities and local practices
- NBS in agriculture build upon a variety of concepts that address traditional challenges in agriculture, related to sustainable production and conservation

Key words

Nature-based solutions, green infrastructure, agriculture, pollution, erosion, agroecosystem

1. Introduction

1.1 Asian agricultural environments at a crossroads

Food systems are key drivers of and subject to multiple, interconnected risks. Food systems comprise various elements - environment, people, inputs, processes, infrastructure, institutions, etc. - and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities including socio-economic and environmental outcomes[1]. Asia as a region achieved considerable success in improving food security outcomes over the past few decades. Public investment in R&D, extension services and rural infrastructure combined with institutional, legal and trade reforms that improved land tenure arrangements, access to farmer credit and economic incentives in agriculture in combination with broad-based economic growth unleased a transformation in agriculture that led to dramatic increases in productivity, poverty reduction and declining levels of food insecurity[2][3].

Despite this progress, food systems in the region and prevailing policy approaches continue to result in sub-optimal outcomes. Hundreds of millions of people are still undernourished. Large proportions of the population suffer from malnutrition[4]. Meanwhile, obesity and overweight are on the rise and diet is a key driver of mortality and disease risk[5]. Policies targeting increased agricultural production and productivity as well as shifts in diets and associated trends across the region have also had significant environmental consequences (Box 1). Incentives to increase production or productivity have led invariably to expansion and/or intensification. Deforestation to facilitate expansion of cropland and plantations in tropical areas of the region has been significant over a number of decades. In other parts of the region, grasslands have been heavily degraded due to overgrazing, invasive species and agricultural expansion.

Agriculture, and associated intensification and land-use change due to expansion, have been also the largest driver of biodiversity loss globally and regionally over the past five decades[6]. Almost a quarter of the region's endemic species are threatened from extinction. Degradation and fragmentation of natural habitats resulting from forest loss is a key underlying driver of this process. Agrobiodiversity is being eroded through losses of pollinators and declines in soil microbiota. Intensification in production systems have further eroded the natural systems on which agricultural and food systems rely. Water stress and scarcity is prevalent in many key agricultural production areas in the region[7].

Related drivers linked to production and productivity are threatening the region's aquatic and marine fisheries resources. Freshwater fisheries are under increasing stress from overfishing, pollution, infrastructure

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[1] HLPE. 2017. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome. [http://www.fao.org/3/a-i7846e.pdf]
[2] FAO. 2018. Dynamic development, shifting demographics, changing diets. [http://www.fao.org/3/I8499EN/i8499en.pdf].
[3] Laborde, D., Lallemant, T., McDougal, K., Smaller, C. and Traore, F. (2018). Transforming Agriculture in Africa & Asia: What are the policy priorities? IISD & IFPRI.
[4] FAO. 2019. The state of food security and nutrition in the world [http://www.fao.org/3/ca5162en/ca5162en.pdf]
[5] Forouzanfar, M.H., Alexander, L., Anderson, H.R., Bachman, V.F., Biryukov, S., Brauer, M., Burnett, R., et al. 2015. Global, regional and national comparative risk assessment of 79 behavioural, environmental and occupational and metabolic risks or clusters of risks in 188 countries, 1990–2013: A systematic analysis for the Global Burden of Disease Study. The Lancet, 386, 2287-323
[6] IPBES. 2019. Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for Asia and the Pacific of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.
[7] Jagermeyr, J., Pastor, A., Biemans, H., Gerten, D. 2017. Reconciling irrigated food production with environmental flows for Sustainable Development Goals implementation. Nature Communications. [https://www.nature.com/articles/ncomms15900]

development and growing prevalence of invasive species. Coastal and marine ecosystems in the region are increasingly at risk from expansion of unsustainable aquaculture, overfishing and destructive harvesting practices. The productivity of the region's marine fisheries are in decline.

As production systems have narrowed in favor of a few key varieties and breeds, production of native varieties has declined across the region leading to reduction of available and cultivated genetic resources. The narrowing of agricultural production systems has also marginalized indigenous and local communities who have often practice co-management strategies that can have benefits for maintaining in-situ biodiversity and genetic diversity in cultivated species.

Emphasis on production and productivity can also undermine the resilience of food systems to external shocks. Asia is particularly susceptible to climate-related extremes and evidence suggests that anthropogenic climate change is driving the increased likelihood and intensity of extreme climate events[8,9]. These risks are expected to grow. Increases in moderate climate extremes, such as larger numbers of warm days and nights, heatwaves and the incidence of intense rainfall at seasonal and daily timescales, have also been observed across the region[10,11].

BOX 1: SELECTED ENVIRONMENTAL OUTCOMES OF FOOD SYSTEMS IN ASIA

Demographics – Population increase: 4 billion (2006) – 4.5 billion (2018)

- Urban share: 42% (2006) – 50% (2018)
- Undernourished: 16% (2006) – 11% (2017) – SDG2

Agricultural production

- Cropland area: 18.0% (2006) - 18.8% (2016) – FAOSTAT
- Number of cattle: 445 million (2006) – 470 million (2017) – FAOSTAT

Erosion and land degradation: Degraded land 24% over total land (2000-2015) - SDG15

Climate impacts and natural disasters:

- Long-term Climate Risk Index (1999-2018)[12]. 7 Asian countries were ranked among the top-10 most affected: *Myanmar, Philippines, Pakistan, Vietnam, Bangladesh, Thailand, Nepal*
- Natural disasters: $57.5 billion (med 2000-2017) – $89 billion (2018) economic losses
- Sea level rise: more than 70% of people living on implicated land are in Asia,
  Under high emissions, up to 630 M people below projected flood levels by mid-century (world)[13]

Water pollution: Progress towards Aichi biodiversity targets (2011-2020) – IPBES

- West Asia: no progress

[8] Jongman, B., Ward, P. J., Aerts, J. 2012. Global exposure to river and coastal flooding: Long term trends and changes. Global Environmental Change 22, 823–835 (2012).
[9] Peduzzi, P., Dao, H., Herold, C., Mouton, F. 2009. Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index. Natural Hazards and Earth System Sciences. 9, 1149–1159.
[10] Lehmann, J., Coumou, D., Frieler, K. 2015. Increased record-breaking precipitation events under global warming. Climatic Change. 132(4), 501–515.
[11] Westra, S., Fowler, H. J., Evans, J. P., Alexander, L. V., Berg, P., Johnson, F., Kendon, E. J., Lenderink, G., Roberts, N. M. 2014. Future changes to the intensity and frequency of short-duration extreme rainfall. Reviews of Geophysics. 52(3), 522–555.
[12] Germanwatch 2019, see Table 2 https://germanwatch.org/sites/germanwatch.org/files/20-2-01e%20Global%20Climate%20Risk%20Index%202020_14.pdf
[13] Kulp, Scott A., and Benjamin H. Strauss. "New Elevation Data Triple Estimates of Global Vulnerability to Sea-Level Rise and Coastal Flooding." *Nature Communications* 10, no. 1 (December 2019): 4844. https://doi.org/10.1038/s41467-019-12808-z.

- South Asia: increase in pollution
- Northeast Asia: increase in pollution
- Southeast Asia: non-significant progress

Agrochemical use - FAOSTAT

- Nitrogen (kg/ha): 100 (2006) – 111 (2016)
- Pesticides (kg/ha): 3.3 (2006) – 3.6 (2016)

Greenhouse gas emissions

- Total annual net emissions 118.5 Gt CO_2 eq by 2030 (scenario without NDC)[14]
- South Asia: 549,000 (2000) – 575,000 (2008) t CO_2 eq from agricultural methane - WB
- East Asia & Pacific: 547,000 (2000) – 697,000 (2008) t CO_2 eq from agricultural methane - WB

Natural Resources:

- Forest area net change: 0.52% (2006) – 0.11% (2016) – SDG15
- Deserts: > 20% degraded (2018) - IPBES
- Grasslands: 60% degraded (2018) - IPBES
- Coral: 1-2% loss per year (2018) – IPBES
- Aquatic species: 37% threatened (2018) – IPBES
- Endemic species: nearly 25% threatened (2018) - IPBES

Source: FAOSTAT; IPBES, Germanwatch and The World Bank Group data

Trends towards increased climate variability and more frequent extremes raise the risks that the food system will be exposed to conditions that result in reduced productivity and that food system assets will be negatively affected. Natural disasters, climate-induced or otherwise, disrupt food production and distribution systems and undermine the coping capacities of food system actors; particularly smallholder producers and marginalized groups. Over time these changes can force the alteration of cropping and land use patterns with flow on effects for food security and nutrition. Such changes may also result in variations in the occurrence of known animal and plant pest and disease outbreaks as well as lead to the emergence of new threats. These in turn can trigger responses that intensify the use of agrochemicals such as pesticides and anti-microbials posing further risks to human, animal, and environmental health as well as food safety.

Transformative and transformational solutions are needed to sustain human needs. To maintain the productivity of our food systems, while addressing the multiple, interconnected risks that food systems are both drivers of and subject to, will require a new transformation (FAO, 2018a). The approaches that have enabled the tremendous productivity growth in Asian agriculture over the past few decades will need to new approaches that will restore ecosystems and safeguard food production for current and future generations. The complexity and scale of food systems implies that there will be no one simple solution. These transformations need to consider the different starting points and pathways ahead, depending on contexts such as country and farmer typology (Stringer et al., 2019), where macroeconomic starting points interact with transformation drivers, such as birth rates and land availability (Laborde et al., 2019).

Positive changes are already underway. The food price crisis in 2008 became a wake-up call for many leaders and scientists regarding the fragility of food systems and the need for *agroecology* approaches, i.e. the ecological sciences to design and manage agriculture sustainably (de Schutter and Vanloqueren, 2011). Such approaches include **system-scale solutions** that can accommodate the various short- and long-term social, economic, political, and environmental priorities (FAO, 2016b; Sonneveld et al., 2018).

[14] Asia-Pacific Forestry Commission. "Twenty-Eighth Session: Forests and Climate Change." Incheon, Republic of Korea: FAO, June 2019. http://www.fao.org/3/ca4936en/ca4936en.pdf.

Moves towards holistic views of agriculture-ecosystems, are an increasingly common feature of global governance instruments including the Sustainable Development Goals (SDG). Under the United Nations Framework Convention on Climate Change (UNFCCC), the Koronivia Joint Work on Agriculture (KJWA)[15] views agriculture and ecosystems as more integrated systems, with soil, livestock, nutrient and water management, production and adaptation-mitigation synergies. Reduced Emissions from Deforestation and Degradation (REDD+) centred around forest carbon (Pitman, 2011; Richards, 2011), and was brought together with more restoration-framed initiatives under the Bonn Challenge[16], which collects nature-based solutions in the Forest Landscape Restoration[17] framework in order to restore multiple functions of forested landscapes. The Bonn Challenge also encompasses the Convention on Biological Diversity (CBD) Aichi Target 15 to restore and build up the carbon stock in 15% of degraded ecosystems by 2020 using Ecosystem-based adaptation[18], and the UN Decade of ecosystem restoration (2021-2030)[19] target to restore 350 million hectares of degraded landscapes by 2030. Building up biological productivity will also benefit crop productivity, it is argued.

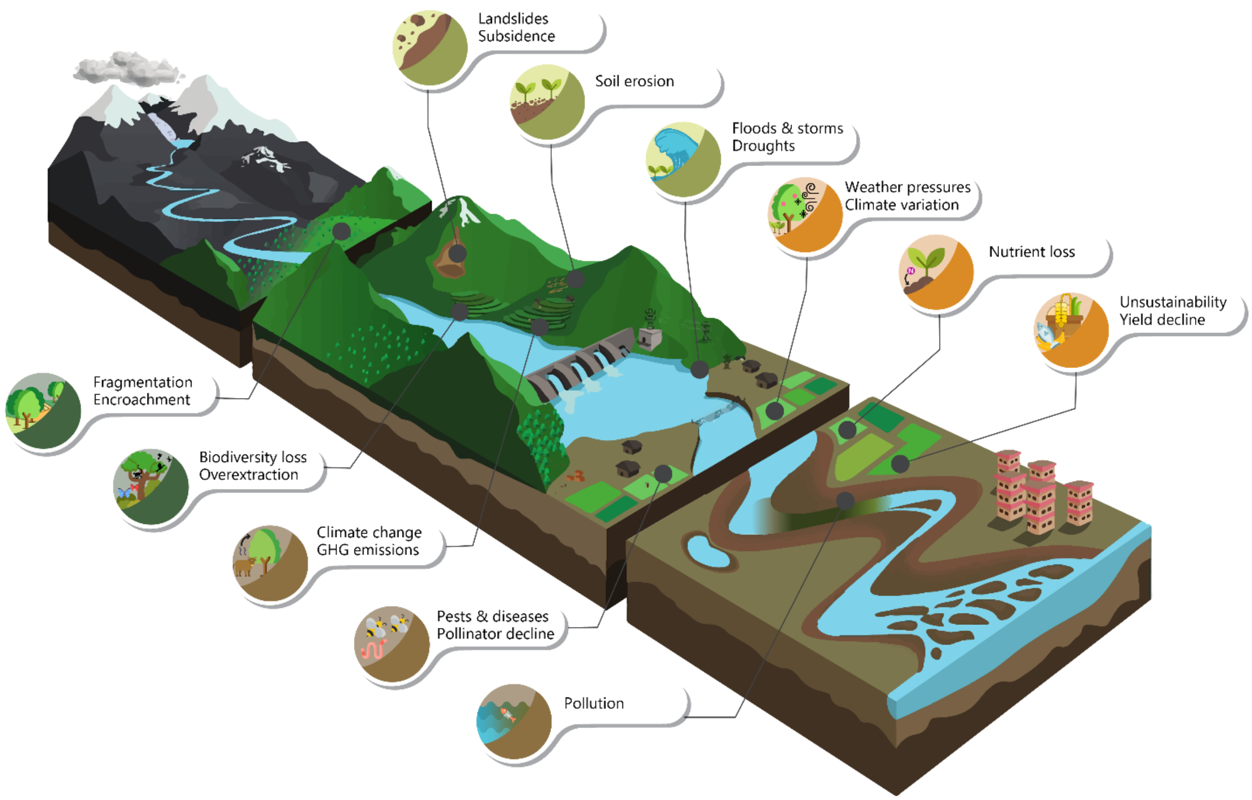
Approaches are called for that build on lessons learned, adapt existing approaches to tackle the complexity of causes to rural poverty, and environmental degradation. For example, ensuring that practices introduced to manage climate risk effectively reduces yield and income variability and leads to farmers escaping chronic poverty Hansen et al. (2019)

While agriculture problems often are solved with on-farm solutions, the root causes of many productivity issues are found at catchment scale, upstream and uphill versus downstream and downhill, forest encroachment, disappearing pollinators. Landscape-based approaches are a more effective unit of attention for transformational action (

[15] http://www.fao.org/climate-change/our-work/what-we-do/koronivia/en/
[16] https://www.bonnchallenge.org/content/challenge
[17] https://www.bonnchallenge.org/content/forest-landscape-restoration
[18] https://www.cbd.int/sp/targets/rationale/target-15/
[19] https://www.unenvironment.org/news-and-stories/press-release/new-un-decade-ecosystem-restoration-offers-unparalleled-opportunity

Figure 1).

FIGURE 1: EXAMPLES OF PROBLEMS FACING AGROECOSYSTEMS, UNSUSTAINABLE AGRICULTURAL PRACTICES (ORANGE), SOIL DEGRADATION (LIGHT GREEN), ENVIRONMENTAL POLLUTION (BROWN), AND DECLINING AGROBIODIVERSITY AND AGROECOSYSTEM FUNCTIONS (DARK GREEN).



Source: Landscape from ICIMOD (http://www.icimod.org/?q=rps_riverbasins). Wave (2.1) Abstract vector created by freepik - www.freepik.com. Landslide (2.3) original icon from www.clipartmax.com. Bee (3.2) and tree (4.1) original icons made by Smashicons from www.flaticon.com. Cow (3.3) icon made by Nhor Phai from www.flaticon.com. All other icons made by Freepik from www.flaticon.com.

1.2A diversity of solutions

A plethora of approaches and frameworks that aim to capture these complex nature-human interactions from different angles have been devised (**Supplementary Table 1**; left column), some with more distinct focus on farming practices, such as *sustainable agriculture* (Daryanto et al., 2018), *ecological intensification* (Garibaldi et al., 2019) *climate-smart agriculture* (FAO, 2013) and others more conceptual, such as, *functional agrobiodiversity* (Delbaere et al., 2014), *ecosystem services* (Holt et al., 2016; Karabulut et al., 2019), *agroecology* (de Schutter and Vanloqueren, 2011), *landscape ecology* (Newman et al., 2019) and *landscape approach* (Holt et al., 2016). Some turn to nature itself to look for solutions. For example, *ecological engineering* uses, mimics, recovers, or modifies ecosystems to reduce or solve a pollution or resource problem in an ecologically sound way (Haller et al., 2018), similar to *ecological infrastructure* (Rosas-Ramos et al., 2018) and *green infrastructure* (GI). The Special Report on Climate Change and Land (IPCC, 2019) classified several integrated land management response options to tackle environmental degradation, climate and food security challenges, including for cropland, grazing land, water, livestock and forestry, agroforestry, biodiversity conservation, wetland and peatland restoration. Griscom et al. (2017) listed 20 *natural climate solutions*[20]*, i.e.* cost-effective conservation, restoration and land management approaches that could contribute to over one-third of mitigation contributions from forest, agriculture, grass- and wetlands. Similarly, Cohen-Shacham et al. (2016) compared ten *nature-based solutions* (NBS) approaches that predominantly focus on the conservation, protection or management of water and forest ecosystems, such as *ecosystem-based adaptation* (EbA) and *ecosystem-based mitigation* (EbM) (Shah et al., 2019). The *Nature's Contributions to People* (NCP) framework was developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and can be described as positive and negative contributions of the living nature, or ecosystem goods and services, for the quality of life to people, while also stressing the role of culture and local knowledge (Díaz et al., 2018). Furthermore, integrating ecological, technological and governance aspects, the *Sustainable Land Management* approach describes the stewardship and use of land resources to meet changing human needs while simultaneously assuring the long term productive potential and maintenance of their environmental functions (Altieri and Nicholls, 2017), similar to *Integrated Land Management* (ILM) and *Sustainable Forest Management* (SFM).

1.2.1 Origins of nature-based solutions and green infrastructure

In the 2000s, nature-based solutions (NBS) gained grounds viewed both as a principle deeply rooted in the ecosystem goods and services discourse (MEA, 2005; Nesshöver et al., 2017), and as a collection of approaches or technologies (Box 2), including green infrastructure (Cohen-Shacham et al., 2016). The term ‘green infrastructure’, however, can be traced back to the 1850s, referring to technologies and construction material that perform similar objectives as ‘grey’ infrastructure, such as water storage or using green belts for wave or wind reduction (Cohen-Shacham et al., 2016). In contrast to grey infrastructure, which typically targets one type of hazard, GI can be applied to complex risk situations that require multipurpose solutions (IPBES, 2019).

The recently launched International Union for Conservation of Nature (IUCN) global standard for NBS (Box 2), which was developed over a number of years, is the most authoritative guide to NBS. The IUCN stresses that NBS is not a substitute for nature conservation; it offers one group of solutions among many, it should support cultural and social values, and it is context specific (Cohen-Shacham et al., 2016 p 6-7). The support of IUCN member states for this standard and the long, collaborative process to develop it is recognition of the potential value of NBS as a way to deliver simultaneous benefits to biodiversity and human well-being (Cohen-Shacham et al., 2016). As such, NBS contribute to both production and preservation of the integrity and intrinsic value of ecosystems (Sonneveld et al., 2018). Recently, it was estimated that NBS with safeguards can provide 37 per cent of climate change mitigation until 2030 with likely co-benefits for biodiversity (IPBES, 2019 p. 10). Additionally, the Global Commission on Adaptation acknowledges NBS for being cost-effective as it offers multiple solutions (GCA, 2019). The Food and Land Use Coalition adopts **nature-based solutions and**

[20] Natural Climate Solutions is also the name of a movement calling for the UNFCCC and CBD to collaborate https://www.naturalclimate.solutions/the-letter

regenerative agriculture among ten critical transitions for making progress towards Paris Agreement and SDGs (FOLU, 2019).

BOX 2: IUCN GLOBAL STANDARD FOR NATURE-BASED SOLUTIONS

Criterion 1: NBS effectively address societal challenges

Criterion 2: Design of NBS is informed by scale

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

Criterion 4: NBS are economically viable

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

Criterion 6: NBS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefitsCriterion 7: NBS are managed adaptively, based on evidence

Sources: IUCN (2020). Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland, Switzerland: IUCN.

Three takes on NBS and GI are compared in Table 1: the one of IUCN, the European Commission (EC) and of the European Investment Bank (EIB). Commonalities include technological solutions which maximize contributions to and benefits from ecosystem services, although the balance may depend on whether human or conservation interests are primary or secondary. The IUCN stresses "conservation norms" (Cohen-Shacham et al., 2016). The EIB makes a categorical cut between NBS and GI as 'natural' and 'man-made' technologies. The European Commission's interpretation of nature-based involve "copy and mimic nature" (EC, 2015), whereby "the delivery of ecosystem services may be natural or 'engineered'" may instead be interpreted as more innovative and open to engineered designs (Eggermont et al., 2015). The latter opens up for greater possible use of green infrastructure.

In the IPBES report, NBS and GI feature primarily in an urban planning context and sometimes the terms are used interchangeably with Ecosystem-based Adaptation (EbA) (IPBES, 2019). The Special Report on Climate Change and Land (IPCC, 2019 p. 739), considers EbA "a set of nature-based methods" for adaptation and food security, closely associated with sustainable land management and water security. This takes us closer to perceiving **NBS for rural and agricultural contexts**.

TABLE 1 DEFINITIONS/PRINCIPLES OF NATURE-BASED SOLUTIONS AND GREEN INFRASTRUCTURE

	Nature based solutions	Green infrastructure
IUCN[21]	1. Embrace nature conservation **norms** (and principles); 2. can be implemented **alone or in an integrated** manner with other solutions to societal challenges (e.g. technological and engineering solutions); 3. are determined by **site-specific** natural and cultural contexts that include traditional, local and scientific knowledge;	Natural and green infrastructure are a subsector of NBS under infrastructure approaches.

[21] https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

	Nature based solutions	Green infrastructure
	4. produce societal benefits in **a fair and equitable** way, in a manner that promotes transparency and broad participation; 5. maintain biological and cultural diversity and the **ability of ecosystems to evolve** over time; 6. are applied at **a landscape scale**; 7. recognise and address the **trade-offs** between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems services; and 8. are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.	
European commission; European Environment Agency (EC, 2015; EEA, 2015)	"actions **inspired by, supported by or copied from nature**; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes." NBS "use the features and complex system processes of nature, such as its ability to store carbon and regulate water flows'" "Restoring degraded ecosystems… can improve the resilience of ecosystems, enabling them to deliver vital ecosystem services and also to meet other societal challenges." (EC 2015)	A "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services". Emphasis is placed on the ecosystem services provided and on **purposeful land designation and management**, with the scope of delivering a range of environmental benefits, including maintaining and improving ecological functions. (EC 2013[22] cited in EEA 2015)
EIB	"Conservation of biodiversity and ecosystems offer nature-based solutions to climate change - **cost-effective, scalable** ways to increase the planet's **resilience** to temperature rises, natural disasters and other climate extremes, and humanity's ability to adapt." NBS to climate change[23] "Using **natural (not man-made) techniques** to either prevent, mitigate or adapt to the effects of climate change. For example, taking advantage of the carbon-sequestering properties of forests to reduce atmospheric carbon dioxide concentrations, using green roofs to reduce the atmospheric heating effects of buildings or re-planting	**Strategically created natural and semi-natural areas,** designed and managed to allow nature to deliver a range of valuable ecosystem services (such as clean air and water), in both rural and urban settings. For example, green roofs, green walls, ecosystem-based rainwater collection, natural flood protection and erosion control.

[22] EC 2013. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions 'Green Infrastructure (GI) — Enhancing Europe's Natural Capital' (COM/2013/0249 final). Cited in EEA 2015.
[23] https://www.eib.org/attachments/pj/ncff-invest-nature-report-en.pdf

	Nature based solutions	Green infrastructure
	coastal areas with native plants to act as natural flood defence mechanisms."	

1.3 NBS for rural and agricultural contexts

Cases in the literature on NBS and GI technologies so far have had a dominant focus on water, disaster-risk management and urban environments (Cohen-Shacham et al., 2016; FOLU, 2019), while examples for agricultural contexts are sparse. In the Special Report on Climate Change and Land, while forestry and water management featured among the five NBS response options on 'land management', none explicitly stated agriculture (IPCC, 2019 p. 946) and in the same report, urban agriculture was instead reported under-management of 'supply' rather than of 'land' (IPCC, 2019 p. 1306).

A review of scientific literature on NBS and related practices described in more detail in Section 2 of this report found that NBS is predominantly focused on the urban sphere. It was found that 88% of the 3500 articles on NBS and GI scanned for this study were focused on the application of NBS in urban contexts. This may be partly because in urban environments the distinction between what is natural and what is human-made, urban infrastructure can be easier to make – at least at a superficial level. In an agricultural context, the distinction between nature and agricultural production systems can be blurry; in part because agricultural systems are often embedded within or adjacent to natural systems and because of the way that agricultural systems rely upon or are integrated with natural systems to maintain their function.

As a result, many agricultural management practices might be thought of as forms of NBS; particularly traditional approaches, which may have enabled some level of balance between productive and other ecosystem services over generations. It is important to acknowledge that (bio-) technical engineering approaches have often been combined with successful "traditional" nature-based practices to try and improve productivity in a given agro-ecosystem or landscape in a manner that could be likened to NBS. Take the traditional sawah systems as an example (**Figure 2**). These are levelled rice fields, connected with inlets and outlets for irrigation and drainage (FAO, 1998 p. 46). Different practices or techniques that could be considered NBS can have different names in different contexts. For example, a "bioswale" in the urban context, a "vegetated drainage ditch" in the engineering context and strips of catch crops among agronomists, share most of the same functionalities, e.g. preventing waterlogging, purifying water and catching sediment (more examples follow in **Error! Reference source not found.**). For these reasons, the NBS concept remains vague and contested (Eggermont et al., 2015; Nesshöver et al., 2017), particularly for agriculture (Sonneveld et al., 2018).

To illustrate the spectrum of degree of human intervention within NBS, the typology developed by Eggermont et al. (2015) reflects how engineering contributions can maximise the return of ecosystem services (

Table 2). These typologies should not be seen as static representations, but rather dynamic benchmarks for many hybrid NBS to enhance their flexibility and problem-solving capacity (Sonneveld et al., 2018). In particular, “design and management of new ecosystems” (

Table 2) serves as a reminder of the unknown solutions to current or future problems (Vermeulen et al., 2013) and the unknown future values of conservation (Lessa et al., 2019). The GI engineering perspective invites rarely featured solutions to common agriculture problems, especially in developing countries. For example, green infrastructure for slope stabilisation, or bioremediation to treat polluted waters entering or exiting a farm.

TABLE 2: TYPES OF INTERVENTIONS WITHIN NBS.

Better use of natural/protected (agro-) ecosystems	NBS for sustainability and multifunctionality of managed agroecosystems	Design and management of new agroecosystems
None or minimal intervention	Partial intervention	Inclusive intervention
maintains/ improves delivery of ecosystem services of preserved (agro-)ecosystems; incorporates areas where people live and work in a sustainable way	develops sustainable and multi-functional ecosystems and landscapes that improve delivery of selected ecosystem services; strongly connected to benefitting from natural systems agriculture and conserving the agroecology	manages ecosystems in intrusive ways includes restoration of degraded or polluted areas using grey infrastructures and engineering approached
Examples: Pollinator flowers, biological pest control, natural regeneration	Examples: Integrated annual-perennial-livestock systems, constructed wetlands	Examples: Green infrastructure for slope stabilization, bioremediation, integrated watershed management

Adapted from Eggermont et al 2015

FIGURE 2: TERRACED SAWAH IRRIGATION SYSTEM WITH IRRIGATION CHANNELS (INSET), BALI, INDONESIA.

PHOTO CREDIT: LAURA NOSZLOPY

2. Approach

This report documents the development of a framework on NBS specifically for agriculture purposes. The overarching principles of the theoretical framework evolved in iterations throughout the literature review (Section 2.1) and a regional stakeholder consultation (Section 2.2). The literature review was conducted to map current theoretical and practical uses of NBS. The stakeholder workshop permitted the gathering of invaluable feedback on the framework and the sharing of examples to enrich the current understanding of benefits and drawbacks and enabling and disenabling factors for the implementation of NBS in the region.

2.1 Literature review

The review of scientific literature was conducted in two steps. First, we scanned ScienceDirect for abstracts and titles with "nature-based solution" or "green infrastructure". This rendered 3511 articles, in which the majority referred to urban environments. Adding "'NOT' urban" the result narrowed to 419 articles, out of which 43 articles were relevant for NBS and GI in an agricultural context. The 43 articles permitted a systematic grouping of practices according to their functions and purpose.

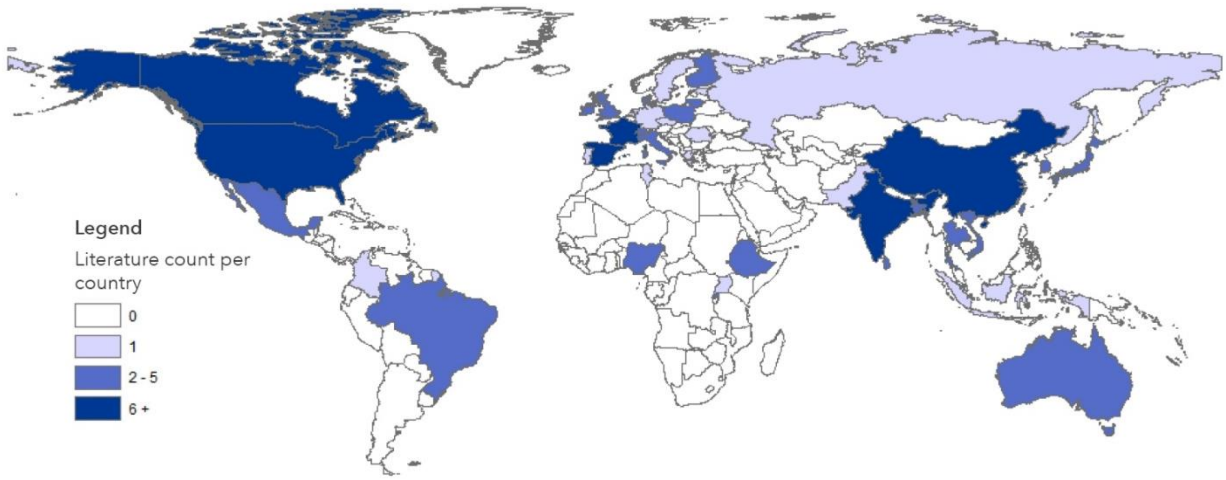
Next, to get more material, we expanded the search to the practices identified as NBS, GI or amelioration, by searching for 'practice name X' 'AND' ["agriculture" 'OR' "fisheries" 'OR' "forestry" 'OR' "animal husbandry"]. With this, literature where the practice was not referred to as NBS or GI was now included. The 25 most relevant results in ScienceDirect for each type of practice published after 2005 were assessed according to our criteria as 'highly relevant', 'relevant', 'some relevance' or 'no relevance' for NBS for Asian agriculture. The content of the most relevant was analysed on social, economic and ecological benefits, as well as policies, spatial and temporal scales, and location. Few of the papers contained detailed socioeconomic assessments. Therefore, a special effort was made to identify trade-offs and adoption aspects.

In total, 181 out of 1450 peer-reviewed articles were subject to in-depth review in this step, along with 7 of the original 43 articles, a total of 188. With this search approach, many practices that have not yet been associated with NBS in the literature were excluded, although they could have high potential. Additionally, related concepts (Supplementary Table 1) were not included, with the goal of reducing bias towards certain subsets. However, it is likely that these search results could have yielded some additional relevant results. In terms of the existing literature, as expected, the majority of practices qualified as "sustainable practices" or "conservation" interventions. Hence, to explore some novel practices for agricultural contexts, we narrow the scope of this report to those that fall under "green infrastructure" and "amelioration".

The reviewed literature represents some global spread (

Figure 3) where a larger share of the reviewed papers were western-based. Despite their relative advantage of a longer data series in the global north compared to the global south, most studies reported for (i) limited spatial (pilot, plot or part of catchment) and temporal scales; (ii) 'one' technology rather than sets of NBS-technologies integrated in a landscape or interconnected; and (iii) monitoring of one or few environmental indicators with limited attention to socioeconomic aspects. This may be due to NBS not yet being an established concept in the agricultural context. For example, many reviewed papers presented unclear or confounded definitions of NBS and GI (if definitions were present at all), which can be viewed against the inconsistent naming conventions with similar practices referred to by different names. The literature review was also limited in terms of livelihoods, social and economic perspectives on NBS. To enrich the discussion, some selected work from other but similar disciplines was included.

FIGURE 3: COUNTRIES REPRESENTED IN THE NBS REVIEW (129 OUT OF 188 PAPERS WITH FIELD EXPERIMENTS, EXCLUDING LITERATURE REVIEWS AND LABORATORY EXPERIMENTS).



2.2 Consultation workshop and testing of NBS framework

The prototype framework emulated through a reiteration of attempts to group practices and ecosystem functions identified through the literature review. The draft framework was tested and modified at the regional two-day stakeholder consultation in Hanoi with 35 representatives of practitioners, policy makers and UN agencies in July 2019. Countries represented in the consultation were: Indonesia, Lao PDR, Myanmar, Nepal and Vietnam.

A major part of the workshop served to discuss the role(s) and objectives of NBS, for instance whether NBS can be a replacement for industrialized monoculture, or whether it can work alongside these systems. Participants also suggested practices which had not been included in the original literature review which could be added, such as biological pest control and pollination.

In view of social dimensions, one important recommendation from the workshop that was incorporated into the framework, is the temporal and spatial scales. The temporal scale means that interventions have effects at different timescales, e.g. short – such as one crop season, medium (1-10 years), or long-term (decades). Planning should take these different timescales into account. Comparisons to non-NBS cannot be direct as the benefits of NBS often emerge on a much longer timescale, while unsustainable practices can bring quick short-term gains, but entail negative longer-term effects. The spatial scale means that interventions can have *in-situ* and *ex-situ* impacts – for example, soil erosion measures implemented at the field level can have *in-situ* (costs and) benefits for the farmer, while other measures have much wider *ex-situ* effects, such as amelioration of pollutants in a river that will be experienced much further downstream. At the largest scale, this can mean the sequestration of carbon, which may have small immediate discernible effects at the field level, but on a global, aggregated level is hugely significant.

Another outcome of the workshop was that participants suggested the framework served two distinct purposes, which should be separated into two: one for classifying NBS technologies and another which can be more directly applied for increasing NBS inclusion in projects. This report presents the former, while the planning tool will be presented in a separate publication.

3. Framework - NBS in agriculture

3.1 Technical dimensions and indicative scales

3.1.1 Ecosystem Functions and NBS

This report expands the view on NBS for ecosystems to include NBS for agroecosystems. The framework is an applied step from the IUCN-criteria (Box 2) towards developing an NBS Project Planning Tool for increasing NBS implementation and a diagnostic assessment tool for NBS. The prototype structure of the framework emerged from bringing the three types of interventions in NBS (

Table 2) together with the ambition to integrate restorative ecological functions in agricultural landscapes (Box 1,

Figure 1).

First, sustainability goals are often limited to production-conservation trade-off discourses, such as sparing versus sharing (Franklin and Mortensen, 2012), intensification versus sustainable production (Matocha et al., 2012), agriculture versus forestry (Adewopo, 2019), or production forest versus regeneration forest (Dewi et al., 2013; Meyfroidt and Lambin, 2009) - which often have conflicting priorities on field versus landscape scales, short-term economic gains versus long-term environmental benefits (Meyfroidt, 2018), and so on. To respond to this deficiency, the framework we propose incorporates practices that contribute to reducing negative trade-offs between **sustainable production and conservation objectives.** This necessarily includes issues of competition and interaction within or between agroecosystems and other ecosystems.

One path for bringing production and restoration objectives closer, goes through land management that deals with weather and gravity-induced damages; green infrastructure engineering solutions and sloping agriculture land technologies share this purpose. Compared to green infrastructure solutions for urban environments, measures for agroecological contexts often fail to make full use of engineering functions of agricultural vegetation as ecological construction material (**Error! Reference source not found.**). **Error! Reference source not found.** illustrates some synergistic opportunities for use of vegetation and green infrastructure by mirroring engineering properties of agronomic crops and production functions of engineering plants in rural contexts, both within and outside of farmland. Another means to bridge production and conservation, goes via using ecosystem functions or elements to remove toxic pollutants in agricultural landscapes.

TABLE 3: ENGINEERING FUNCTIONS OF VEGETATION

Engineering function	Vegetation requirement	Agronomic GI equivalent	Civil engineering GI equivalent
Catch eroding material (soil, rocks) moving down the slope by gravity or water	Strong or dense, flexible stem	Hedgerow, bamboo	Catch wall Bamboo mesh with natural forest regrowth
Armour slope against surface erosion from runoff and splash erosion	Low canopy	Grass cover, e.g. arachis pintoi	Revetment; Vegetated stone pitching

Engineering function	Vegetation requirement	Agronomic GI equivalent	Civil engineering GI equivalent
	Dense surface cover, small leaves		
Reinforce soil to increase resistance to shear	Extensive, dense fibrous root	Densely rooting perennial fodder grasses, shrubs and tea hedgerows along contours	Reinforced earth
Anchor surface material by extending roots	Deep, strong vertical roots	Deeply rooting shrubs and trees	Soil anchors
Support soil mass by buttressing and arching	Extensive, deep wide spreading roots Many strong fibrous roots	Buttress by clumping bamboos at base of slope; cut & carry grass for micro terracing	Retaining walls

Adapted from: Clark and Hellin (1996)

Benefits to people. Regardless of practice, adoption is almost always dependent on perceived benefits to livelihoods. Benefits from agroecosystem and ecosystem services will be prioritised differently by different groups of people. While there may be diverse societal interests amongst the immediate beneficiaries, such as land users and land owners, those interests may also need to be negotiated with direct and indirect, and often disconnected, ecosystem services to the wider society. Many of the people living in the most exposed areas have vital knowledge about its ecosystems (Simelton and Dam, 2014; van der Wolf et al., 2016). Despite this, in Asian agricultural contexts, poverty and immediate needs can drive farmers to put pressure on already degraded ecosystems through unsustainable practices (IFAD, 2013). NBS-design should be guided by inclusiveness, local needs, knowledge and aspirations as an integral part of the solutions (Cohen-Shacham et al., 2016; Richards, 2011). Improvements of agroecosystem functions should be evident as livelihoods improvements (Gawith and Hodge, 2019).

Temporal connectivity of benefits. Few sustainable development concepts seem to offer practical intermediate solutions for enhancing livelihood security of poor land users whilst at the same time restoring ecosystems. Traditional Asian examples illustrate how farmers weigh livelihoods and environmental benefits, such as taungya systems where annual crops are intercropped with perennials until trees produce fruits or timber. Lessons can be learned from interventions which have evolved into permanent integrated systems, such as parkland agroforestry (Gold et al., 2013), and specifically how to overcome perceptions of lack of short term economic gain (with solutions often framed as “not economically beneficial for x years”).

Spatial connectivity of benefits. Benefits and values of ecosystem services that prevent e.g. upstream-downstream water and sediment transport or transboundary spread of pests and diseases, may be overlooked or negligible if the spatial delineation or return periods are too narrow. In rural landscapes multiple types of interventions can co-exist within larger ecosystem(s). These can be connected using agroecological principles according to their *synergies* and *interconnectivity (Bentrup, 2008*). A central part of this is temporal and spatial connectivity.

For instance, **sequencing** can be referred to as temporal and spatial purposeful planning. It includes layout of vegetation, animals and/or structural components that simultaneously return improved functioning of agroecosystems and generate benefits to land users in the present and the future. Sequencing builds on managing three interaction principles:

- to decrease competitive interaction between the components of a system, e.g. roots competing for water or nutrients, canopies competing for light, roaming animals among newly planted seedlings;
- to optimise supplementary interaction, adding a component without reducing the benefits of another, e.g. introducing nitrogen fixing multifunctional trees or crops in a maize field; phytoremediation or catch crops surrounding fields can be used as fodder, prevent agrochemicals from entering water sources, and do not interfere with the main crop in the field;
- to optimise complementary interactions by mutual benefits, e.g. leguminous cover crops reduce weeds and fix nitrogen; multistorey systems with microclimate and soil-and-water conservation interactions, pest management and agrobiodiversity which contribute to yield stability or income diversification.

Drawing on the definitions in Table 1 and

Table 2 for the purpose of this report, we describe NBS in general as "the use of natural processes or elements to improve ecosystem functions of human-altered environments as a primary or secondary purpose". From this we specify NBS in agriculture as **"the use of natural processes or elements to, over various temporal and spatial scales, improve ecosystem functions of environments and landscapes affected by agricultural practices, and enhance livelihoods and other social and cultural functions".** Agricultural practices are defined here as the cultivation of crops, animal husbandry, forestry and fisheries.

We let this description be a guide, rather than a strict definition, acknowledging that many agricultural practices serve multiple main functions, and it may not be not possible or desirable to make clear-cut distinctions. Moreover, the purpose may depend on the stakeholder. To reap the most benefits for agricultural ecosystems which are by definition altered and managed by human action, the goal is to achieve well-managed or restored ecosystems with solutions that use, are inspired or supported by nature. Here, both agroecosystems, agroecosystems interfacing with natural ecosystems, and natural ecosystems are considered. Take water in an agriculture landscape as an example. Water — entering or exiting one field can come from, or continue to, a lake or river (a natural ecosystem) or another field (a managed agroecosystem). Equally, while passing through the field, different management options can alter the quality and quantity of water entering, within, and exiting the field (Figure 1). Thus, NBS for agriculture is seen as a collection of approaches (

Table 2) that, over various temporal and special scales,

- improve the use of existing ecosystems;
- improve the management of ecosystems; and/or
- create new agroecosystems; and
- benefit rural livelihoods, while recognising that traditional knowledge, technical approaches, and new innovative solutions are equally needed and valued.

3.1.2 Problem based logic of NBS

NBS imply a focus on problem solving. Therefore, a core assumption underpinning an NBS approach is that natural systems are being or have been transformed by human interventions and the process of transformation is leading or has led to degradation and loss of ecosystem functions. As outlined above, this assumption is often well founded in the case of major agricultural production systems.

Differentiating between problems that manifest and their underlying root causes is also necessary. It is understood that there are likely to be trade-offs involved between the four typologies. Therefore, a problem description with observed evidence and root causes should be agreed upon through a process of consultation before identifying solutions.

Framing NBS: Building from thinking in landscape level approaches (Hobbs et al, 2014), we can frame the choice of whether and when to adopt NBS as requiring a priori consideration of issues such as:

- The degree to which a production system or landscape is being degraded by current management approaches;
- The risk that, if unchecked, further degradation will result in dangerous or irreversible depletion of ecosystem functions;
- The availability and feasibility of NBS options that can mitigate or reverse degradation in agroecosystem functions;
- The likelihood that NBS interventions can succeed in restoring or reversing degradation;
- The level of support from system-specific stakeholders for different NBS options;
- The relative costs and benefits of NBS compared to other interventions.

Consideration of the issues above implies the need for a multidisciplinary, diagnostic assessment and prioritisation of problems to enable cost-effective targeting of solutions and their sequencing and connection.

Reconciling the spatial and temporal scales of NBS: Many land management technologies have multiple functions and provide synergy benefits. The qualifier is the prioritised main functional intention of the design and the management. The establishment of an ecologically functional system can be achieved by systematically building up ecosystem functions through different components over time (succession) or joining areas (connectivity). However, synergies and trade-offs in space and time will differ from the perspective of humans and the environment as well as among worse- and better-off groups within populations.

Ensuring NBS delivers benefits to people. Any NBS-intervention should aim to benefit livelihoods, wellbeing and equal opportunities using metrics and indicators that local communities have identified. Social and cultural contexts are not generalizable. Therefore the main message here is in line with the IUCN criteria (Box 2), to carefully identify winners and losers of an NBS intervention, and to promote transparent and participatory processes. Numerous guidelines have been issued in support for transparent processes to avoid that inequalities are cemented or aggravated, and for promoting equal opportunities to the process and the outcome (e.g. CBD, 2019; Colchester, 2010; FAO, 2012). Here, the benefits to people and environment are considered mutually valuable: NBS-interventions in agriculture are unlikely to progress without (monetary and non-monetary) benefits to people. Conversely, benefits to people are unlikely without the NBS-intervention gradually incrementing the environmental status. Consequently, NBS should result in reduced environmental debts.

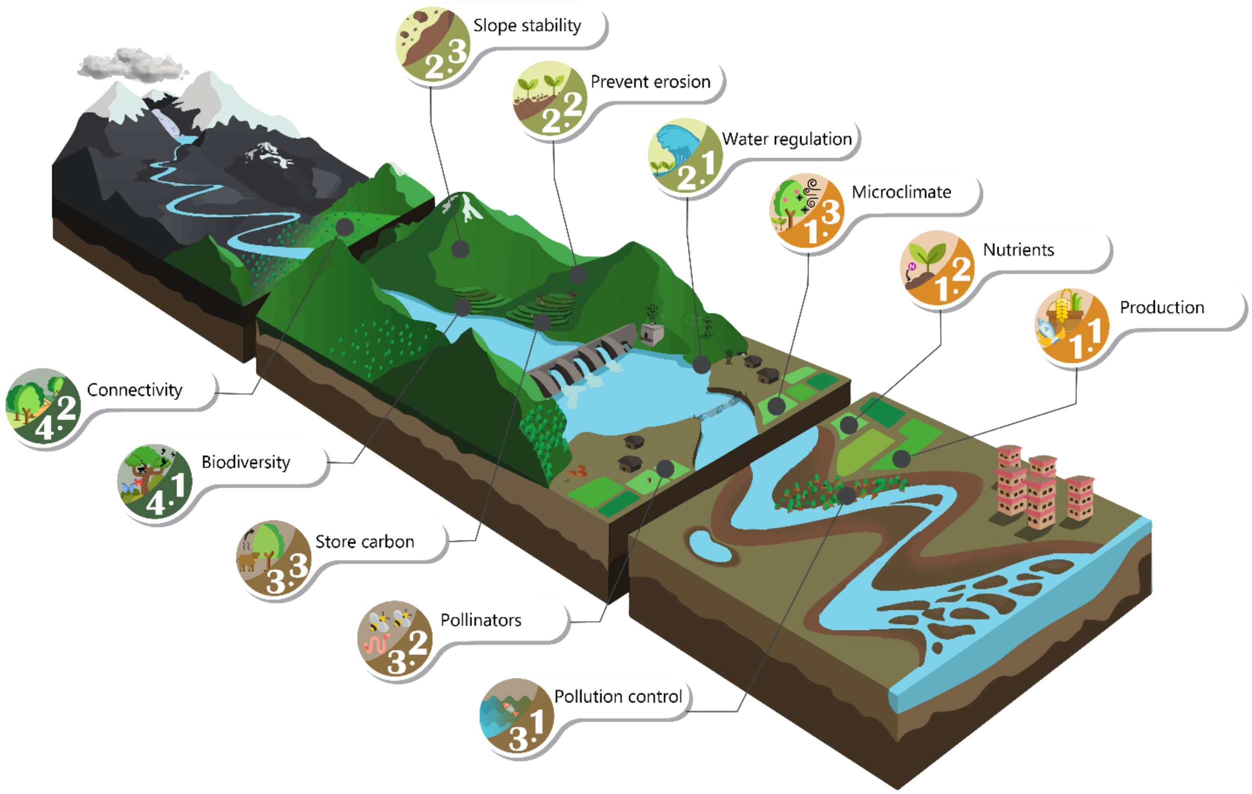
3.1.3 An NBS framework for agriculture

After iterations throughout the review and workshop, four distinct categories for introducing NBS in agriculture emerged, with ten subcategories (

Figure 1; Figure 4; **Error! Reference source not found.**):

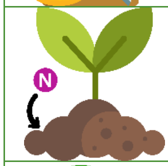
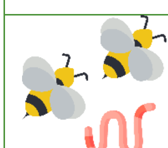
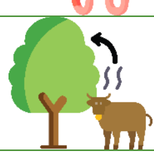
- production – the use of NBS primarily for production purposes that emphasize synergies with ecosystem services, e.g. agroforestry and windshields
- green infrastructure - NBS measures are installed primarily for engineering purposes as an alternative to grey infrastructure and may be designed to deliver ecosystem services, e.g. for slope stabilization or integrated watershed management;
- amelioration - the use of either naturally occurring or deliberately introduced organisms with the primary purpose of improving or restoring the (toxic) condition of plants, soil, water, or air (bioremediation and phytoremediation) including climate change mitigation, e.g. reducing greenhouse gas emissions or sequestration of carbon; and
- conservation - the use of NBS primarily to maintain or increase ecological health, with a strong focus on biodiversity functions, goods and services, e.g. (agro-) biodiversity conservation, natural fallow, pastures and grasslands, natural regeneration, or buffer zones in national parks. May include setting aside land areas under management for protection, to prevent disturbance or to secure (agro-) ecosystem values in other parts of the landscape.

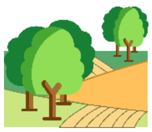
FIGURE 4: NBS FOR ASIAN AGRICULTURE LANDSCAPES. THE NUMBERS ARE FOUND IN TABLE 4.



Source: Landscape from ICIMOD (http://www.icimod.org/?q=rps_riverbasins). Wave (2.1) Abstract vector created by freepik - www.freepik.com. Landslide (2.3) original icon from www.clipartmax.com. Bee (3.2) and tree (4.1) original icons made by Smashicons from www.flaticon.com. Cow (3.3) icon made by Nhor Phai from www.flaticon.com. All other icons made by Freepik from www.flaticon.com

TABLE 4: THE NBS FRAMEWORK

Solution type and essential function		Nature-based solution - contributory mechanism	Problems addressed (list not exhaustive)	Indicative spatial sca of impact	
				Unit	peop
1. Sustainable practices *Must have a productive element*		1.1 Sustain or increase agricultural **production** by means other than standard approaches to the availability of water or nutrients, or plant breeding	Unsustainable intensification Increased variability in yields Declining yields	Field	Householc and f
		1.2 Retain or increase available **nutrients** in soil, water and plants, in plant-or animal-available forms	Soil fertility decline Nutrient loss from the agricultural system	Field	Householc and f
		1.3 Improve **microclimate** at the soil surface or in the cropping zone, by beneficial regulation of any combination of moisture, humidity, air movement or temperature	Weather or climate pressures or variations	Field or landscape	Householc and f Commu vulnerabi well-b
2. Green infrastructure *Must have a structural engineering function*		2.1 Regulate **water flows** (energy, rate or volume) on soil surfaces, in soil masses and at water body peripheries	Floods and droughts Storms, typhoons and cyclones Saline intrusion and sea level rise	Field or catchment	Householc and f Commu vulnerabi hea
		2.2 Prevent **soil erosion** by armouring a slope or watercourse bank, or by catching eroding material (safeguard topsoil quantity)	Soil erosion Disrupted river sediment balance	Field or catchment	Householc and f Commu vulnerabi hea
		2.3 Enhance **slope stability** against shallow mass failures by roots or other natural products increasing soil shear resistance, anchoring through failure planes and supporting soil masses by buttressing and arching (safeguard soil masses)	Slope failure and landslides Land subsidence	Field or landscape	Householc and f Commu vulnerabi well-b
3. Amelioration *Must have a beneficial biochemical, biological or microbial function*		3.1 Remove, degrade or contain **pollutants** in water, soil or air through any one or combination of natural physical, chemical or biological agents (bio- and phytoremediation)	Toxic pollution from agriculture activities Toxic pollution affecting agricultural production	Field or catchment	Householc and f Commu vulnerabi hea
		3.2 Restore or stimulate beneficial **biota** for soil health, pollination or pest control, in the soil, cropping zone or nearby environment	Pests and diseases Pollinator decline Reduction in soil (micro)biota activity or function	Field	Householc and f
		3.3 Remove or store atmospheric **carbon** in soils or plants	Effects of climate change GHG emissions from agriculture	Global	All soci vulnerab climate c
4. Conservation *Must have a species*		4.1 Increase or protect **biological diversity** and habitat, either wild or modified (field scale)	Biodiversity loss Monocultures leading to decreases in crop genetic resources Over-extraction of natural	Field	Householc and f

Solution type and essential function		Nature-based solution - contributory mechanism	Problems addressed (list not exhaustive)	Indicative spatial sca of impact	
				Unit	peop
preservation benefit			resources Invasive species		
		4.2 Enhance **connectivity**, **area** or **health** of ecosystems (large scale)	Fragmentation and loss of habitats Encroachment and habitat conversion Degradation of natural resources	Catchment or landscape	Commu vulnera health ar bein

Source: Landscape from ICIMOD (http://www.icimod.org/?q=rps_riverbasins). Wave (2.1) Abstract vector created by freepik - www.freepik.com. Landslide (2.3) original icon from www.clipartmax.com. Bee (3.2) and tree (4.1) original icons made by Smashicons from www.flaticon.com. Cow (3.3) icon made by Nhor Phai from www.flaticon.com. All other icons made by Freepik from www.flaticon.com.

3.2The NBS framework for agriculture

The two types of purposes that frequently appear in the literature and easily lend themselves to be contrasted, are production and conservation oriented. Nevertheless, NBS are multifunctional. For example, perennial systems could contribute to all four NBS-categories listed above. Specific practices from the literature review and identified key contributions are summarised in Supplementary Table 1 and stated in more detail in Supplementary Table 2.

3.2.1 Sustainable practices

Production

Production-oriented practices make use of the multiple ecosystem functions of trees, plants and (wild or domesticated) animals for agricultural production, while minimizing the negative environmental impacts of the production (Daryanto et al., 2018) such as regenerative agriculture and conservation agriculture.

Nutrients, microclimate

Practices can be aimed at retaining or increasing available nutrients or improving the microclimate. For example, trees in alley cropping can provide shade among other roles: (i) tree crops for food and fodder production, (ii) perennial alley crops, (iii) trees for crop facilitation via shade, and (iv) within-system tree diversity (Wolz and DeLucia (2018). Many sustainable practices drawing on agroecological principles (Altieri, 1992; FAO, 2018a) or collectively referred to as climate-smart agriculture (FAO, 2013; Rosenstock et al., 2019), would fall into this category. Specifically, in agroforestry and sloping agriculture land technologies, in addition to production contributions, plants may also perform green infrastructure functions if, for example, planted as grass strips, or nitrogen-fixing legumes used as green mulch and fruit trees, planted along contours (Are et al., 2018; Geussens et al., 2019; McIvor et al., 2017). Production decline of crop *e* is a common concern once it is intercropped with crop *y*, and Land Equivalent Ratio is a common index to compare the return of both *e* and *e*, with the area needed to grow both separately, rather than yield of crop *x* (Mead and Willey, 1980). Updated versions allow weighing of for example farmers' perceived wellbeing indicators.

3.2.2 Green infrastructure

In the reviewed examples, green infrastructure practices were used for structural stabilization of slopes and controlling the flow of water and soil at field or catchment scale. Green infrastructure often entails the use of selected species which maximize their GI purpose such as root structure and morphology for erosion control, slope reinforcement or wave energy reduction. In the non-agriculture sphere, one main purpose of green infrastructure is disaster prevention or adaptation, such as preventing or restructuring after landslides.

One of the most common GI examples are wetlands. For example, in the US and New Zealand, ecological infrastructure of wetlands included riparian forest, floodplains and constructed wetlands (Watson et al., 2016) (Mander et al., 2005). Mangroves can have both direct and indirect benefits such as coastal protection and adaptation for both urban and rural livelihoods, small-scale fishery, and ecosystems (Diop et al., 2018; Rahman and Mahmud, 2018; Tran and Bui, 2013).

Agronomic measures

When agriculture species play the role of vegetation in GI, multiple functions are rendered. For example, grass strips control soil erosion and return crop yields (Are et al., 2018) and vetiver grass can act as phytoremediation to trap phosphorous (Huang et al., 2019) whilst providing cut for animal feed. The efficiency of a catch crop also depends on physical elements, such as slope gradient (Novara et al., 2019) and root structure. Some papers related micro-terraces and built terraces as green infrastructure for agriculture (Zuazo et al., 2011) (Liu et al., 2018). In northern India for example, simple weed strips and weed mulch also created micro terraces, which resulted in reduced soil erosion and higher yields (Lenka et al., 2017). The suitability of a wetland for agriculture activities is a trade-off amongst its current and desired ecological condition, the type of management schemes that can be implemented, characteristics of the catchment and socioeconomic settings (McCartney et al., 2005).

Engineering structures

Agricultural waste can also be used as construction material for green infrastructures. For example, geotextiles made from local material such as bamboo, rice and wheat straw, and maize stalks were used to stabilize slopes in Lithuania, China, Thailand and Vietnam, sometimes in combination with contour planting, with reported higher biomass production and crop yields, compared to no geotextiles (Bhattacharyya et al., 2012).

The Global Centre on Adaptation states that nature-based or hybrid solutions (combinations of green and grey infrastructure) are more adaptable to changing climate conditions, often cost-effective and low-regret adaptation options. Specifically, a better connection of socioecological issues with engineered solutions can contribute to climate and biodiversity goals (GCA, 2019).

3.2.3 Amelioration: Phyto- and bioremediation

Phytoremediation - the use of living green plants, and bioremediation - the use of microorganisms to remove, contain, break down or degrade contaminants, are considered cost-effective, multifunctional, and environmentally friendly technologies for cleaning up polluted sites or preparing sludge before it is reintroduced to the environment. In the US and Indonesia, a set of methods to control agricultural runoff, such as vegetated swales, enhanced stream buffers, denitrifying bioreactors, and constructed wetlands were referred to as GI (Anbumozhi et al., 2005), while here their main functions count as amelioration. Many bio- and phytoremediation interventions are local, and many studies are species-focused.

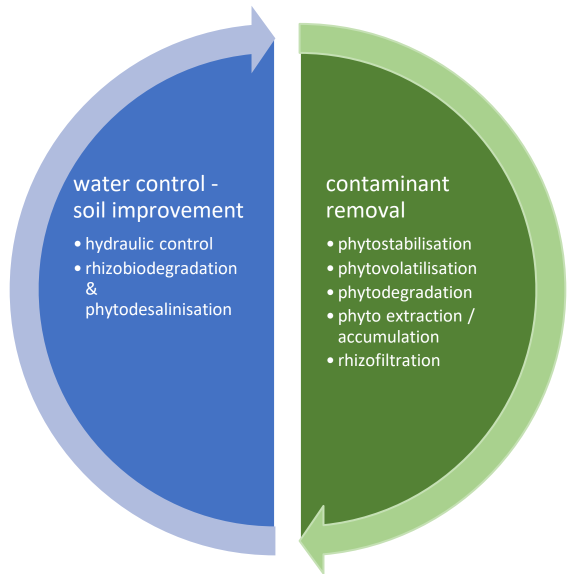
Bioremediation

The number of patents for new bioremediation technologies for water and soils are increasing at a fast rate, especially in China. A review showed that patents for using bioremediation agents, such as bacteria, enzymes, and fungi were more common than algae, plants and protozoa, as most patents targeted oil contaminants (Quintella et al., 2019). Specifically, in agricultural environments, anaerobic denitrifying bioreactors (hydraulic retention and biochar) can remove agricultural pollutants such as pesticides from farmland and surface waters (Hassanpour et al., 2019; Villaverde et al., 2018). A majority of the 25 papers on bioremediation the literature review, were concerned with removing nitrates. Moreover, only three Asian countries were represented: China (5), India (1) and Pakistan (1). More relevant to the Asian context could be the use of rice straw instead of woodchip as carbon source in the bioreactor, which has shown promising results (Liang et al., 2015).

Within bioremediation, site selection and design are two important aspects. For example, denitrifying bioreactors require design that is resistant to differences in water flow during storm events to avoid leakage (Pluer et al., 2019). Among the literature featured many laboratory experiments, which suggests that this is an area where new and more advanced technology can be expected.

Phytoremediation

FIGURE 5: THE TWO MAIN FUNCTIONS OF PLANTS IN PHYTOREMEDIATION PROCESSES



Based on Jonsson and Haller, 2014.

In phytoremediation (**Figure 5**), plants are purposely selected to extract pollutants from soil and water, or to exclude pollutants from biomass, or a combination of both (Jonsson and Haller, 2014). Fourteen studies on phytoremediation were identified through the search. The primary objectives were pollution control and desalinization.

The extraction capacity of plants also informs on the potential use of plants for feed or food. For example, to recover pesticide contaminated cotton soils in Nicaragua, scientists compared the distribution of persistent organic pollutants in different vegetative organs in three cultivars of amaranth. Overall, the stems and leaves accumulated higher concentrations than the roots and seeds, however the type and amount of pollutant that the each cultivar extracted from the soil varied significantly (Haller et al., 2017). Another example of the use of agricultural crops for phytoremediation is the uptake of antibiotics in maize (Zhang et al., 2019a). A common tree in Southeast Asia for phytoremediation is *Shorea spp*, which coincidentally also has many red-listed varieties.

In constructed wetlands, different riparian vegetation types such as coniferous, deciduous broad leaf or evergreen broad leaf forests, aquatic or herbaceous plants play different roles that are designed for controlling and managing water pollution (Wang et al., 2018). To optimise the removal of toxic agrochemical content and avoid phytotoxicity in the purifying plant, phytoremediation in constructed wetlands with *Phragmites australis* may perform better together in combination with other technologies such as bio-mixtures with coconut fibre, compost and soil (Gikas et al., 2018). Functions of riparian zones and buffer strips and their designs are well described by Mander et al. (2017). Depending on the habitat, the width of the vegetated buffers may vary between 1 to 4000 meters to effectively protect water sources and crops against pesticides . Such detail however, is not reflected in legal documents (Gene et al., 2019).

Climate Change Mitigation

Land management practices for the purposes of above and below ground carbon sequestration were added to the amelioration category after the expert workshop. While many of these practices have main production or conservation purposes (e.g. FAO, 2016a; Hernández-Morcillo et al., 2018; Rosenstock et al., 2018; Zomer et al., 2016), their contributions to climate change mitigation were seldom the main priority in the reviewed NBS and GI practices. Conversely, they are seldom referred to as an NBS or GI in the literature search. One good example is hedgerows, which increase soil organic carbon but often struggle to get recognition as a mitigation contributor (Hernández-Morcillo et al., 2018). Lacking in the NBS and GI review were the inclusion of proactive pathways and considerations such as avoided forest conversion, avoided wood fuel and avoided peat impacts. These also benefit air, biodiversity, soil and water quality in addition to mitigation (Griscom et al., 2017).

Despite policy and funding mechanisms, including the Bonn Challenge with REDD+, the scale of interventions necessary for a significant global impact are difficult to monitor, conflict with landscape diversification or compete with other land uses and ecosystem goods and services (Cohen-Shacham et al., 2016; Namirembe et al., 2015). Reduced greenhouse gas emissions are an – underestimated - co-benefit from numerous NBS-practices. Conversely, tree-planting initiatives with diverse and permanent stands create additional ecosystem services.

3.2.4 Conservation

Biological diversity

For the conservation category, the main purpose is to build up connected ecosystems and biodiversity, temporarily such as natural fallows, long-term or permanently, such as natural forest regeneration. Various landscape approaches aim to achieve multiple goals from *ecological intensification* of crop production with biodiversity focus (Garibaldi et al., 2019) to ecosystem services within *PES-schemes* (Holt et al., 2016; Karabulut et al., 2019). One particular intention with practices in this category, is to ensure ecological connectivity of conservation agriculture on field-units across larger landscape mosaics in landscape approaches (Holt et al., 2016). A list of 35 databases with over 100,000 plant species is found in van Noordwijk (2019, p. 29). Furthermore, species diversity play important roles for recovery after disaster and preventive disaster risk reduction, such as mangroves protecting against storm surges (van Noordwijk et al., 2019).

Connectivity

The review illustrated the integration of practices to connect patches in the landscape. First, in Europe with functional agrobiodiversity approaches, where permanent grassland and crop diversification within ecological focus areas involved a certain per cent of arable land that was set aside to be used for field margins, hedges, trees, fallow land, landscape features, biotopes, buffer strips, and afforested area (Delbaere et al., 2014).

Similarly, connectivity was achieved with ecological infrastructures, such as woodland hedges, rosaceous hedges, grass strips, wildflower strips, and field margins (Rosas-Ramos et al., 2018). In Pakistan, an example of EbA included practices such as crop rotation, intercropping, agroforestry, crop diversification, live fencing, and wind barriers by trees (Shah et al., 2019). The example illustrates a combination of practices that build up multiple ecosystem values over time. Furthermore, as is seen from these examples, many biodiversity conservation practises also contribute to ameliorative functions, such as carbon sequestration and pollinators (IPCC, 2019).

Succession models

The process of connecting or expanding NBS-measures to cover larger time scales and areas of the landscape is intended to be captured in the conservation category. However, the reviewed literature on NBS reported mostly on smaller implemented projects or the planning of larger scale projects. This may explain that few examples involved multiple spatial or temporal scales, such as species composition (Wolz and DeLucia, 2018), successions or sequencing of interventions, or possible trade-offs in the build-up of agroecosystems.

Relevant in this context, two major arguments for resilience of agroecosystems are avoiding the crossing of ecological thresholds, a stage when ecosystem functions are disturbed and rapidly change, and planning robust NBS-interventions in agroecosystems that are anticipated to last for decades. A study from the US on climate-induced forest stand dieback, suggests that there are complex linear and non-linear relationships between biodiversity, ecosystem functions and ecosystem conditions (Evans et al., 2017).

Succession models for designing and planning interventions are more common in natural ecosystems, but also exist for production systems and restoration of agroecosystems (Bourgeois et al., 2016; McCartney et al., 2005; van Noordwijk, 2019). Prioritisation of measures includes the identification of the sequencing order for a stable succession. These are optimised temporal and spatial arrangements that draw on biochemical and biophysical synergies of vegetation and other ecosystem elements interactions as canopies and roots develop. The sequencing balances their demand for water, light and nutrients until their intended functions are ready or an equilibrium is reached. For example, natural regrowth and root development in riparian wetlands take years (Frątczak et al., 2019) and the full effect of trees for slope stabilisation cannot be expected until decades later (Stokes et al., 2010). Timing the interventions depends on natural regeneration processes, but also when and which benefits are expected. Succession models can help negotiate or guide among least-worst options (Toensmeier, 2016, p 67), when it is not necessary or advised to implement all measures or maximise return on all functions at once. An example of a landscape planning tool is the open access WaNuLCAS[24]. This model simulates water, nutrient and light capture interactions and has been used widely across Southeast Asia, including in northern Thailand, to optimise tree-crop interactions for soil conservation measures (Pansak et al., 2010).

[24] http://old.worldagroforestry.org/downloads/WaNuLCAS/WaNuLCAS4.0.pdf

3.3Socioeconomic dimensions of NBS

3.3.1 Economic dimensions

An overarching critical barrier to adoption of NBS as viewed by the participants at the consultation workshop (Box 3), could be summarised as "what [indirect economic benefits] will motivate farmers to adopt NBS, especially when [environmental] benefits are found off-farm?". Intuitively, NBS and GI interventions need to make an economic argument for adoption, from the perspectives of both farmers and decision makers in Asia. Nevertheless, only ten reviewed papers included economic assessments of the practice itself or of the environmental values of the practices. Among these are economic estimates calculated on management approaches to reduce sediment loads (Mtibaa et al., 2018) and agriculture runoff (Gikas et al., 2018; Irwin et al., 2018). A study in Tunisia by (Mtibaa et al., 2018) found that while contour ridges alone halved the sediment yield, the most cost-effective option was a combination of practices, including buffer strips, conversion to orchard, and grass strip cropping. Similarly, (Gikas et al., 2018) showed that two low-cost options with plants in constructed wetlands, performed better when combined with bio-mixtures containing coconut fibre for bio-purification. Other estimates, such as those by Irwin et al. (2018), related the improvement in water quality from reduced agriculture runoff with an associated value for residents and recreation users. Here, ten percent improved water quality resulted in a 'lifetime cost benefit ratio' of 2.9.

This shortcoming in economic assessments can be accounted to, firstly, difficulties in correctly evaluating ecosystem values. For example, the effects and valuation of agroforestry ecosystem services were clearer at the farm/plot scale, whereas attribution easily gets blurred in mixed land uses at landscape scale (Kay et al., 2019). Second, there are difficulties extrapolating results from smaller empirical studies, e.g. the role of pollinator services for global scale food production. To overcome this, Melathopoulos et al. (2015) devised an approach to estimate values of pollinator services from three different assumptions: (i) the degree of dependency of crops on pollinators; (ii) pollinators need different habitats and pollinate different crops (wild versus domesticated) hence the cost to retain them will vary; (iii) the degree of alignment of the price of the ecosystem service with the risk, e.g. the value depends on the probability of a collapse. Third, underlying economic assumptions of grey versus green infrastructure depend on how risk, investment costs and value of losses are calculated. For example, Onuma and Tsuge (2018) tried to determine when green infrastructure is preferable to grey for disaster risk reduction. They did this by developing parameters to compare the two options in view of hazard, population potentially affected, and associated vulnerability. Although their focus was not primarily on agriculture, similar valorisation principles can have applications for GI in agriculture. For example, grey infrastructure is designed as defence to one particular natural hazard and breaks at a certain magnitude, while mixing grey with green infrastructure as back-up can be more durable. Additionally, costs are often lower for recovering green infrastructure after an event. Lastly, NBS interventions need to consider surrounding land-use change, such as increasing land rents on intensive agriculture land, which will likely drive costs for conservation and carbon credit compensations (Phelps et al., 2013). Adding a long-term lens is as critical as the probability of a practice itself to contribute to ecosystem recovery.

The review found few cases on economic valuation of NBS from Asia. One review paper pointed out that many studies, especially in developing countries, fail to specify baseline conditions to which cost-effectiveness evaluations are made. This is arguably partly due to a shortage of available georeferenced data on agriculture management, costs and prices (Ovando and Brouwer, 2019). Data shortage also risks misinterpreting conservation *vis-a-vis* production interests, where the historical management contexts are required to understand the ecological values and trade-offs (Angelstam and Lazdinis, 2017; Naumov et al., 2018), not the least in the light of potential tenure issues (Borelli et al., 2019; Carter et al., 2017; FAO, 2016b). Furthermore, the ongoing rapid land-use changes across Asia may make it difficult to determine a baseline or an "ecological equilibrium" to reflect "ecological health". Bearing in mind that many smallholder farmers are change averse, better assessments of the Cost and Benefits and Loss and Damage inferred from Business As Usual, could make a stronger case for the need to change practice and bring more light on what the new interventions are intending to achieve. Promoting policies and insurance schemes for diverse ecosystems is generally new, poorly understood and lacking longitudinal observation data for making calculated risks and benefit assessments. Here, ongoing work on piloting insurance schemes within EbA may have some relevance for NBS in agriculture (GIZ, 2019).

3.3.2 Social and cultural dimensions

Returning to Box 2 and the criteria of NBS as addressing and seeking synergies with other interventions to "societal needs", being "stakeholder-inclusive", producing "societal benefits", we notice that few of the reviewed NBS-cases examined non-economic social or cultural dimensions at depth. This may be that researchers focused more on the practices than the social processes. Here, we shortly discuss why this is a problem and how it can be addressed.

First, several studies suggest that farmers may not adopt sustainable practices despite having witnessed ecosystem benefits, because of increased initial costs, labour inputs, or customs and preferences (Cerdà et al., 2018; Chapman and Darby, 2016; McWilliam and Balzarova, 2017). In short — a combination of economic, attitudinal and farm structural factors are relevant and apply to a range of situations from riparian buffer zones in the EU (Buckley et al., 2012), to coastal zone management in Southeast Asia (Joffre et al., 2015). On the other hand, if interventions were selected purely based on economic cost-benefit models, there is a risk that the root causes of degradation to the environment remain unsolved.

Second, in many of the reviewed NBS cases implemented at larger scales, the boundaries between natural and agroecosystems are fluid when it comes to control over land and resources. In contrast to NBS for urban or natural ecosystems, this public-private interface potentially adds layers of complexity to a framework for NBS in agriculture. Here, past experiences with REDD+ and PES in developing countries can exemplify how trade-offs between production, social and rural development ambitions and environmental restoration objectives have been addressed. Additionally, they can exemplify ways to ensure that the rights of smallholder households are appropriately included in legislative and negotiation processes. Finally, they can show how existing inequalities owing to social status and class, landless and land-owning farmers, customary and statutory tenure systems, or gender disparities were reduced. Much can also be learnt from the functioning and organisation of many traditional practices. Examples include the negotiation of aspirations, the joint management of resources and ecosystem trade-offs, the continuous adaptation to new environmental conditions of farmers in Globally

Important Agriculture Heritage Systems (GIAHS)[25], and community-based initiatives such as adaptation or forest protection, or irrigation schemes, such as sawah (**Figure 2**).

Third, diverse stakeholders' interests are highly contextual and difficult to generalize. Particularly when larger-scale NBS-interventions are initiated, principles of transparency are important regardless of the public or private nature of programs. The process of problem formulation, definition of goals, and identification of concrete interventions needs to be inclusive. For example, we highlight how both economic modelling and selection of stakeholder representatives can limit the search for options. Farmers willingness to adopt new practices can be influenced by cost-benefit assessments of different management options, as shown in an example with cover crops (Daryanto et al., 2018). A system-dynamics modelling study on paddy field management from Vietnam explored the dynamics between farmers and their rice agriculture operations, focusing on the role of fluvial sediment deposition within their dyke compartment (Chapman and Darby, 2016). The study found that triple-cropping was only optimal for the wealthier farmers and in the short-term, while sluice gate management to enable soil nutrient replenishment would be a more economically and environmentally sustainable practice.

Despite a vast body of literature concerned with piloting different types of compensations for land use conversion, particularly payments for ecosystem services (PES), few mentioned NBS. In Uganda, Geussens et al. (2019) investigated farmers' willingness to accept eight practices (qualifying as sustainable production or green infrastructure in this paper: i.e. minimum tillage, mulching, contouring, trenches, grass strips, agroforestry, and riverbank protection) under nine different compensation levels, or PES contracts. The study had two important lessons for NBS. First, it showed that the biggest difference between willing and reluctant PES-adopters, concerned their perceived benefits of minimal tillage, riverbank protection, and mulching. Their preferences depended not only on the intervention, but also on the compensation level, and whether they received community funds or individual compensation. Second, among the considerations that the project designers had to make were willingness to adopt versus the reduced effectiveness of practices when they were too scattered. Hence, a minimum number of farmers were required. The willingness to accept was high when the need for a different solution had reached a certain threshold, such as severity of degradation (the Uganda example), or when farmers have run out of other viable options. Ultimately, PES schemes would benefit land uses with high ecosystem values by combining marketable and non-marketable ecosystem services, such as biomass production and groundwater, soil quality, carbon sequestration, or penalising land-uses with dis-benefits (Kay et al., 2019).

3.3.3 Trade-offs and synergies

Illustrating complex trade-offs in transparent ways can help to reach negotiation solutions. For instance, Rosa-Schleich et al. (2019) reviewed the economic and environmental trade-offs among nine diversified farming practices (**Figure 6**). For each practice, they first developed a matrix of ecological and economic benefits, which were then converted into two axes. The space showed what clusters of practices were perceived to give high ecological benefits (agroforestry), high economic benefits (structural elements), or high in both (organic agriculture). Similarly, for the purpose of restoring an environmentally degraded mangrove ecosystem in Bangladesh, scientists developed a relative environmental and economic matrix with a quantitative cost-benefit study on four silvo-fishery systems under different restoration scenarios: integrated mangrove-shrimp, crab-

[25] http://www.fao.org/giahs/en/

mangrove, mangrove bio-filtering, and nypa-shrimp over three periods between 0 to 10+ years (Rahman and Mahmud, 2018). Both studies showed that combinations of practices with multiple functions are beneficial, particularly when the introduction of structural elements have insignificant economic or productive motives. Moreover, interventions that require decades to mature, such as mangrove restoration, also strongly depend on community participation and governance commitment (Rahman and Mahmud, 2018).

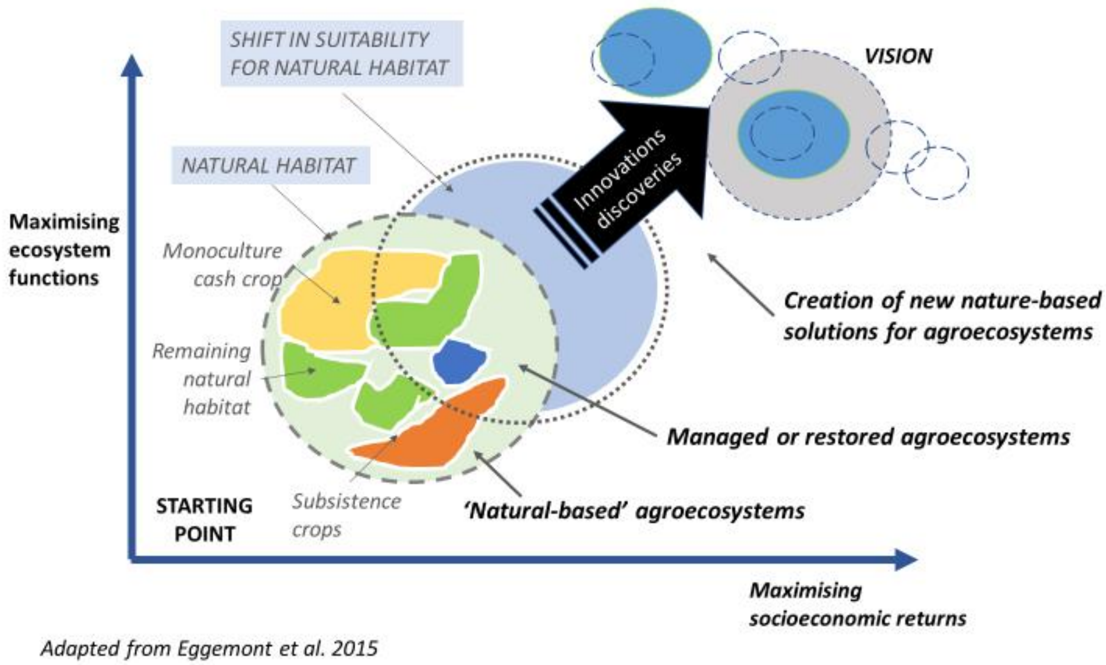


FIGURE 6: THE OPPORTUNITY FOR NBS, AS A COMBINATION OF NATURAL AND MANAGED SOLUTIONS, TO MOVE TOWARDS MORE MAXIMISED ECOSYSTEM FUNCTIONS AS WELL AS SOCIAL AND ECONOMIC VALUES. X-AXIS: EXAMPLE OF SOCIOECONOMIC VALUES OR BENEFITS AT FARM SCALE: YIELD QUALITY, YIELD STABILITY, LONG-TERM EFFECT ON YIELD, SAVINGS ON AGROCHEMICAL INPUTS, MACHINERY, OR LABOUR, WELL-BEING. Y-AXIS BENEFITS OF ECOSYSTEM FUNCTIONS FOR THE FARMER: BIODIVERSITY, POLLINATION, PEST CONTROL, DISEASE INCIDENCE, WEED CONTROL, SOIL HEALTH, EROSION CONTROL, NUTRIENT AVAILABILITY, WATER REGULATION, CARBON SEQUESTRATION, RESILIE**NCE. ADAPTED FROM (EGGERMONT ET AL., 2015; ROSA-SCHLEICH ET AL., 2019; SUSSAMS ET AL., 2015) AND**

TABLE 2.

3.3.4 Policy dimensions

Among the evidence for long-term adoption and transformation, the review raised examples of where NBS-practices were embedded in institutional and policy decisions that went beyond subsidies and conservation goals. For example, Albert et al. (2017) identified four premises for economic valuation of ecosystem services: (1) an institutional analysis to establish uses of nature and incentives of different stakeholders, (2) cost-and-benefits analysis associated with the change in nature, (3) analysis of public and private sources of incentives to land managers, and (4) trade-off assessments between societal goals to establish winners and losers coming with the policy package. The benefit of long-duration policies was shown similarly in an 18 year-long study from Italy, which concluded that through a persistent government policy, the different needs of different farmer typologies could be met, from early to late adopters (Gatto et al., 2019). Their study on implementing and maintaining hedgerows, reported that early adopters required that the compensation could be integrated with their income-generating activities, while the next group of adopters were those who received support to plant new hedgerows rather than those who maintained their existing ones. The third phase of adopters were motivated by social pressure and public acknowledgement of farmers' work, and the late adopters followed when they felt pressure from neighbour farmers rather than the public. The role of governments for setting policies and long-term pathways is repeated also for regulating public goods where PES-markets are limited, such as fish and fish habitats (Mulazzani et al., 2019).

Some reviewed studies stated that blanket policies fail to reflect the complex realities and trade-offs (Holt et al., 2016). The stakeholder consultation workshop therefore, generated more practical insights (Box 3). First, underlying causes of farmers' reluctance, such as control over resources, are rarely addressed and instead generally "solved" by training and sensitization. Specifically, tenure insecurity is known to restrict smallholder farmers' longer-term investments in diverse perennial farming systems (Borelli et al., 2019). Second, existing governance barriers, such as rigid policies and institutional silos, are overlooked in many studies. These barriers also demotivate stakeholders. For example, a structured analysis within seven Indonesian government institutions identified broad gaps and inconsistencies for institutionalizing valuation into policy (Phelps et al., 2017). Consequently, while NBS is interdisciplinary per definition, policy recommendations rarely reflected those complex realities or presented concrete nexus issues.

Third, the workshop participants were largely in agreement that sufficient, stable and long-term support was lacking for landscape-scale NBS across Asia. The importance of this as a precondition included Vietnam's national PES policy, which after almost a decade of implementation still has difficulties reaching impact at scale. Among the reasons raised were that no compliance is required, and the net benefits are so low (fixed, non-negotiable compensation) that often only community-based payments are viable to payout. Furthermore, community compensation is often preferred by the poorer households, and unlikely to motivate adopters in the long run if living standards improve. Incentives and policies to change from short to long-term sustainable behaviours are urgently needed, notably from government and/or companies buying the products. Studies suggest, that since PES compensations are generally low and may be subject to changing compensation levels, (wealthier) farmers who do not need payments, should not receive them even if they make interventions (Geussens et al., 2019).

Agriculture and rural development policies can actively redirect subsidies from extractive monocultures and support the promotion of ecosystem services (Gawith and Hodge, 2019).

Decision support and policy analysis tools

Tools for negotiating trade-offs in multifunctional landscapes have potential practical application for NBS (Holt et al., 2016). Numerous tools have been tested handling the cascade relationship between environmental management, ecosystem goods and services, human wellbeing and environmental governance (Phelps et al., 2017). A concrete example is to use decision support tools for comparing when GI is preferable to grey infrastructure (Onuma and Tsuge, 2018). This can be translated into loss and damage recommendations from, for example, (economic) assessments of benefits from GI for flood control (Watson et al., 2016), or post-disaster assessments of impacts on watershed services and water security (HLPE, 2019). For example, spatially explicit policy trade-off models were used to map and assess the landscape potential to best sustain natural pest control (Rega et al., 2018). Participatory workshops and multi-criteria analyses (MCA) are often used to assess policy impacts on ecosystem services (Saarikoski et al., 2016). However, in an attempt to test the coherence among eleven sectoral policies in Europe, discrepancies and agreements between results generated from MCAs and a cross-cutting strategy (nexus) approach of energy, water, food and ecosystems showed that the latter approach better captured synergies and conflicts between policies (Karabulut et al., 2019). Similarly, a two-step solution scanning approach first involved a set of participatory workshops to scan options to address a certain challenge. Solutions were scanned for their contribution to climate change (directly and indirectly) and sustainable agroforestry. Next, an expert consultation prioritised the solutions. This process identified the agroforestry practices with the most potential to contribute to adaptation and mitigation, namely those improving soil-organic matter, such as hedgerows and windbreaks. Agroforestry training and safe economic routes were identified for reducing educational and financial barriers (Hernández-Morcillo et al., 2018). Decision support tools seem to be used in the initial stages of research projects, while the review gave little evidence for them becoming permanently integrated in decision processes. This reflected the stakeholders' difficulties in achieving long-term policy structures.

Some common tools used for biodiversity and ecosystem services assessment could be adopted in NBS planning. The Toolkit for Ecosystem Service Site-based Assessment (TESSA)[26], for example, currently includes a number of ecosystem services, such as global climate change regulation, water services and coastal protection, harvest wild goods and cultivated goods, nature-based recreation, pollination services and cultural services. Bagstad et al. (2013) reviewed 17 ecosystem services models and concluded that many were too resource intensive for routine use in public-private decision making. Among the models was Artificial Intelligence for Ecosystem Services (ARIES)[27], an online tool with global coverage for mapping ecosystem services and flows. The two manuals on Social and Biodiversity Impact Assessment for REDD+ projects for social and biodiversity impacts, respectively, are great resources for project-based methodologies focussing on forest biodiversity (Pitman, 2011; Richards, 2011). The last example, the *agrobiodiversity index* collects a status score of agrobiodiversity in production systems and markets, a country-level progress score on commitments, and identifies risk areas (Bioversity International, 2019). This index also introduces genetic resource management for future options. Matrices can

[26] https://ipbes.net/policy-support/tools-instruments/toolkit-ecosystem-service-site-based-assessment-tessa-v20
[27] http://aries.integratedmodelling.org/

be strong tools for communicating trade-offs and uncertainties in clear messages to policy makers, including linkages between agriculture and regional status of Aichi biodiversity targets (IPBES, 2018)(Supplementary Table 1).

3.4Specific considerations for NBS for agriculture in Asia

The workshop participants voiced certain aspects that were not captured well by the literature review. While discussants recognised an urgency for NBS-like interventions in agriculture, some concerns were particularly instructive (Box 3) and generated some suggested ways forward viewed from implementers and decision makers' perspectives (Table 5).

3.4.1. Put people in the centre

Concern: Two differences between Asian and the western-oriented case studies were raised. First, studies from European landscapes and ecosystem services often have the general public integrated as beneficiaries of cultural services, such as recreation and well-being. Nevertheless, the motivation to accept uncertainties involved with changing practices, can vary considerably even among homogenous groups of farmers, as shown in several European studies (e.g. Gatto et al., 2019). Conversely, in studies from developing countries, farmers and local communities were the primary and often only users and beneficiaries of ecosystem services, and rarely interacted in negotiations with the larger society. Workshop discussions (Box 3) and many case studies centred on farmer communities and their livelihoods playing the double roles of being negatively affected by environmental degradation and at the same time being the adopters of NBS, regardless of the root cause of the problem. This runs the risk of making NBS technology oriented and supply-driven, rather than outcome oriented and demand-driven, and could make 'lack of capacity' a legitimate barrier for adoption among reluctant farmers. Parallels were observed among participants to western examples of opinions about practices not being profitable, e.g. when Italian farmers associated hedgerows with reduced planting area (Gatto et al., 2019).

Second, many concepts or frameworks, such as ecosystem services, agroecology, climate-smart agriculture and NBS, have not had the chance to mature to become fully mainstreamed in policies in the Asian context. Therefore, although technically many practices adhering to these concepts are known, the concept of NBS is new and must go through a policy integration cycle, which stalls the momentum of the process.

Ways forward: When farmers experience demand for a product, they often find their own ways to overcome technical capacity gaps.

To avoid being met with reluctance and seen as "another new concept", its purpose needs to be clearly communicated. People-centred frameworks were perceived to have better chances for implementation and wider uptake, than concepts considered as top-down, complex, vague, technocratic, or bureaucratic.

3.4.2. NBS as agriculture 4.0

Concerns: The focus of NBS is delicate. If NBS is promoted as a replacement for industrialized monoculture, it risks being viewed as a 'disruptive' solution. Conversely, too much livelihoods focus risks becoming 'another' development project that takes focus away from environmental degradation (Box 3). Where the priority is food security and farmers themselves are responsible for improving their livelihoods, investments in conservation and environmental upgrading would need to be cost-shared. Last, NBS can be designed to address many common and transboundary agro-environmental problems. However, an over-reliance on best practices recommendations can hinder creativity and may result in maladaptation. Furthermore, to opt for scaling of best-practices may not always be desirable or achievable given the diversity of situations and problems in any specific agricultural area and community.

Ways forward: If NBS can appear alongside monocultures, it can be "mainstreamed" into large-scale agriculture landscapes to mitigate some of the most harmful impacts, described as "agriculture 4.0" during the workshop. One selling point is to convey how environmental problems caused by agriculture (e.g. overuse of agrochemicals spilling into waters) and environmental impacts on agriculture production are interrelated (e.g. polluted soils and water impacting on pollinators and food safety).

The workshop discussants agreed that Asia needs to learn from successful cases and to deliver evidence that engage and motivate a wide range of stakeholders, public and private, producers and consumers. More transparent value chains were seen a precondition, where social media was perceived to remove some distorted market information, especially when the policy development process was too slow. Rural development policies can shift from agricultural outputs, and in particular monoculture practices, to ecosystem services (Gawith and Hodge, 2019).

Adding a stronger rights and co-investment perspective to the NBS framework, the Responsible Investment in Agriculture and Food Systems (RIAFS) could offer a set of non-binding principles to promote responsible investments that specifically contribute to food security and nutrition. Prepared by the Committee on World Food Security, the principles build on guiding frameworks on rights, livelihoods and tenure (CFS, 2014) and have several overlaps for NBS. Particularly, in relation to Principle 6 "Conserve and sustainably manage natural resources, increase resilience, and reduce disaster risks", NBS does represent a set of environmentally sound practices that also can reduce the negative impacts of agriculture. For this to happen, it will require breaking up some silos, a common terminology and international policy frameworks. One example to illustrate this process is the development of ASEAN agroforestry guidelines where ministers agreed on a regional strategy with subsequent national work (Catacutan et al. (2018) and Singh VP (2016)). Other guidelines for integrating a number of commitments and higher-level policies exist, for example for EbA and disaster-risk reduction (CBD, 2019).

3.4.3. Identify possible entry points for NBS in Asian agriculture

Concern: Although positive spill-over effects on adoption were noted over time in some European studies (Gatto et al., 2019), the prerequisites for NBS-adoption in Asian contexts need to be better understood.

Ways forward: Proof of evidence is vital for the initial adoption. Details of the required evidence needed must be worked out with stakeholders as it likely depends on their interests. Approaches need to be worked out that can accommodate both stable policies that motivate change *and* community engagement that ensures local problems are addressed. This calls for inclusive diagnostic tools that can identify and monitor ecosystem degradation.

Opportunities to promote a transition from short to long term impacts can be pursued, for instance, through environmental economics accounting, "green GDP", or capping a maximum for environmental debts that can be moved into the future. High level officers may be motivated if NBS can attract climate funding such as from GEF, GCF, and the Adaptation fund. The framework is a first step to facilitate such intentions.

The workshop attendants identified human and environmental health as a potential "urgency trigger" that could be demanded or pushed by both consumers and stronger farmer organisations. The motivation to implement new adaptation measures is often higher within the first year after damage, among both farmers and local authorities (Le et al., 2018), hence certain practices may only be adopted once a certain ecological (or economic) state worsens in a location or group.

BOX 3: LIMITS TO WIDER USE OF NBS IN ASIA

- **from implementer's view-points**

Economic motivators

- **Risk compensation to farmers.** If there is no compensation to the individuals for the risk they have to take, then what is the incentive?
- **Short-term needs.** Farmers have short term needs, such as subsistence and livelihoods but less capacity to invest in longer-term gains.
- **High investment cost or low profitability** compared with traditional practices. Access to (or knowledge about) markets/low demand
- **Limited access to finance and markets.** The government needs to support local farmers to sustain ecosystems

Land-use regulations

- It is often mandated to grow annual crops, such as rice, in certain landscapes (including varieties and management), which limits the range of NBS-solutions. Other restrictions can include contract farmers.
- Awareness, technical knowledge, conflict with traditional practices

Labour intensive. If NBS appears as demanding labour inputs, or requiring volunteering community or group work, it may demotivate some, such as farmers, government officers and private sector, to participate in the implementation

- **from decision makers' view-points**

NBS is new

- Weak technical capacities. Limited knowledge and awareness, low customer demand, limited benefits evidenced by farmers. **Lack of evidence (at scale).**
- **Trade-off between long-term and short-term benefits.** Benefits of NBS may be in 20-30 years. If NBS fails to deliver on immediate goals, e.g. x% of GDP growth for agriculture, ministers may not get re-elected.
- **Commercial viability** is unclear. The short-term profit return is unclear compared to high initial costs.

Governance

- **Political will and sectoral agendas.** Agriculture and environmental sectors operate in parallel but have contradictory agendas. Countries may have some environmental policies but lack enforcement mechanisms. Insufficient legal framework supporting NBS.

Finance

- **Market demand** versus government regulation. Even if the government wants to encourage NBS, the market may not follow. For example, consumers' taste may prefer non-organic to organic products, as has been seen with tea.
- **Big loan incentives.** GI can reduce the size of a loan, because it is not large-scale grey infrastructure. Therefore, are the banks motivated enough?

Source: Expert workshop July 2019

TABLE 5: POTENTIALS FOR NBS FROM IMPLEMENTERS' AND DECISION-MAKERS' POINT OF VIEW, WITH REGARDS TO GENERATING AND COMMUNICATING EVIDENCE AS WELL AS GOVERNANCE AND POLICY ASPECTS.

Potentials for making NBS more attractive…	Evidence generation and communication	Governance and policy
…from implementers' viewpoint	○ **Proof of profitability or compensation** ○ **Evidence and training**. Involve service providers ○ **Market demand for sustainable production** ○ **Healthy environment** and sustainability for **livelihoods** ○ **Positive imaging of NBS.** There should be knowledge sharing and awareness programmes to make the benefits of NBS clearer to the public.	○ **Government support** and/or **financial incentives** ○ **Favourable policy.** The government can support favourable policies for NBS, by for example giving tax exemption
…from decision makers' viewpoint	• **Generate evidence.** Clear economic and long-term benefits need to be clear and convincing both to policy makers and the public, such as on climate change, disaster risk reduction. • **Closer to the community and continuous engagement.** There needs to be higher profit and availability to the communities.	• **Concrete commitment.** If NBS results in slower GDP growth, this may be acceptable if it is costed against a clear long-term benefit. This requires external push, guiding binding commitments to forego short-term economic gains for longer-term benefits • **Finance and policy.** Trying to integrate NBS into global finance projects, e.g. GEF, GCF and implement NBS via top down policy frameworks, e.g. UNFCCC may be faster and more uniform. Support tools to integrate NBS into government's planning process. Peer-pressures to create positive imaging and international branding may make decision makers more knowledgeable about and positive to NBS. • **Make NBS attractive to the financial community,** it needs to be profitable and commercial. If NBS cannot make itself attractive to the banking sector, funds need to be taken from different sources.

Source: Stakeholder workshop July 2019.

4. Conclusions and needed action

This report has attempted to outline a possible normative framework for nature-based solutions in agricultural systems; particularly in an Asian context. The development of the framework has come from the need to address the growing interest in NBS as a potential tool for needed transformation in different sectors and as a response to the gap in specific tools and guidance on how NBS applies in an agriculture sector context.

It is important to acknowledge that the elements that make up the NBS framework for agriculture are not new. Each element of the framework builds upon a variety of concepts that address traditional challenges in agriculture, related to sustainable production and conservation. What the framework does offer, which is new and of potential wider value, is the way it allows for a more coherent assessment of agroecosystem degradation across spatial and temporal scales and the formulation of multidisciplinary responses capable of restoring or maintaining the agroecosystems that underpin agricultural livelihoods. NBS for agriculture is an umbrella that allows for the organization and comparison of approaches that draw upon a range of technical disciplines and stakeholder perspectives to improve the use and functionality of (agro-) ecosystems (Figure 6).

The framework is not intended to solve all challenges at all scales. The problem-based logic that underpins the framework presented in this report is geared towards practical applications that are likely best targeted at landscape scale and/or sub-national levels. The framework may not, for example, translate easily into dedicated national policies for NBS. However, NBS approaches targeting improvements in ecosystem functions aggregated across a range of production regions in a given country could make tangible contributions national policy priorities for climate resilient and low emission agriculture as well as land-use restoration, conservation of biodiversity and, ultimately, sustainable development.

Despite growing interest in NBS at the global level, concrete applications of an NBS approach specific to agriculture will be needed to demonstrate its potential value in a management context. An implementation, and learning-oriented approach is needed, that encourages experimentation and context-specific creativity to improve NBS applications and adoption to address apparent or emergent risks. At the same time, NBS should incorporate an evidence-based approach based on targets for improvements in ecosystem functionality, clear metrics and iterations of data collection, information, communication and advocacy.

The literature review in this report and the case studies presented at the regional workshop indicated that NBS approaches to date have been small in scale and focused on marginal lands at the fringes of major production landscapes. The full potential of NBS requires wider application including adoption in major production landscapes that are the drivers of more significant agroecosystem degradation. A gradual approach, based on decentralized piloting and demonstration NBS approaches in a wide range of ecozones and socioecological contexts, would allow a fabric of small-scale cases to be connected in a process of exchange, adaptive learning and motivation through the networks, and through ecological interconnectedness (illustrated in Figure 6 by circles upper right). The NBS-framework could also serve to inspire the documentation of promising variations of designs and practices for an overarching program of action at larger scales.

To be effective, applications of NBS in agriculture will also require the support of a wide range of actors in the production landscape including farmers, communities and resource managers, local government extension workers and advisors at farm and landscapes scales, downstream value chain actors at local and global levels and national policy makers. Strategic partnerships of actors, public and private, based on mutual interest in restoring major production landscapes through NBS are needed to ensure that application of NBS approaches have wide support and the most potential to lead to lasting change in management practice. Linked to the point above, the formation of strategic partnerships based on production systems with high levels of need in terms restoration will help define potential partners to engage in developing NBS applications.

4.1 Needed action

Looking ahead there are a number of opportunities to deepen the understanding and application of NBS in agricultural production systems. The table below (Table 6) outlines categories of needed actions and possible concrete examples. The framework developed in this report can provide needed guidance to inform this work.

TABLE 6 CATEGORIES OF NEEDED ACTIONS AND POSSIBLE CONCRETE EXAMPLES

Action	Concrete Examples
Develop diagnostic assessment tools with applied assessments of key landscapes, to identify where there is potential to implement NBS. Tools need to be flexible enough to capture the contexts for NBS over space and time, including trade-off analyses of winners and losers, impacts on agriculture production and on natural ecosystems.	▪ The NBS framework presented here, and an NBS Planning Tool provided as an Appendix, are provided as initial tools that can be further adapted. ▪ Development of practical guidance for implementation of NBS, based on diagnostic assessments.
Identify and agree upon landscapes to target for NBS applications particularly landscapes with high levels or risk of agroecosystem degradation based on agreed intervention criteria and potential for NBS adoption.	▪ Review the status of degradation across agricultural landscapes and prioritize sectors with the highest environmental costs for NBS interventions. ▪ Apply NBS diagnostic assessments in the preparation of project design exercises targeting restoration of agroecosystems such as the GEF-7 Food Systems and Land Use Restoration programme.
Set up multidisciplinary networks with ongoing NBS sites for application and demonstration of the NBS framework and related approached. and including awareness raising activities, capacity building and exchange tours.	▪ Use participatory integrated landscape designs and simulations to help to build up functional ecosystems with values that also motivate land users over time. ▪ Create dialogue platforms for value chain actors to understand how NBS approaches can deliver wider value for value chain level recognition (e.g. branding or product narratives) and resilience
Implement complimentary NBS approaches via action research, participatory experiments and scaled-up actions to complement existing	▪ Participatory, multidisciplinary integrated landscape designs and simulations to help to build up functional ecosystems with

Action	Concrete Examples
development projects and loans with an NBS outlook.	values that also motivate land users over time. ▪ Integrate indigenous knowledge and approaches into a suite of NBS options for agriculture. ▪ Set up phytoremediation recommendations to prevent agriculture runoff into waters and reservoirs, for different problems and with species for different purposes, e.g. compost, feed, bioconstruction material. Measure the change in labour inputs.
Establish regular longitudinal monitoring and reporting systems for NBS-sites to study on-site and peripheral impacts, (before,) during and after project completion, including reporting on people's indicators of wellbeing. Monitor benefits and disadvantages of larger adoption of NBS over different spatial and temporal scales.	▪ The NBS Monitoring Tool provided as an Appendix, is provided as an initial tool that can be further adapted.
Where relevant, link NBS work in agriculture to policy processes including national policy priorities linked to the SDGs as wells as global processes on NBS such as IUCN's NBS standards and the NBS Initiative	▪ Develop cost/benefit analysis of NBS applications in agriculture to allow for easy comparison of NBS and traditional approaches ▪ Organize policy consultations to identify and review purposeful qualification criteria and indicators of NBS for agroecosystems. ▪ Ensure local indicators contribute to national reporting targets, e.g. NDC.
Identify ways to scale-up NBS via traditional, public funds and innovative financing mechanisms.	▪ Set up competitive start-up or innovation funds for your agri-entrepreneurs to invest in new marketable nature-based solutions.

1

Appendix

Supplementary Table 1. Synonymous generic terms and their interpretation in the NBS framework

Supplementary Table 1

Generic terms	Interpretation in the framework for NBS in agriculture
Conservation agriculture	Sustainable practices
Climate-smart agriculture	Sustainable practices (depend on the CSA practice)
Low emissions agriculture	Sustainable practices (mitigation)
Organic agriculture	Sustainable practices
Resilient agriculture	Sustainable practices
Sustainable agriculture	Sustainable practices
Landscape approach	NBS on a larger scale
Landscape ecology	Similar to NBS without agriculture focus
Functional agrobiodiversity	Synonym to NBS
Nature's contributions to People (NCP)	Synonym to NBS, with cultural focus and focus on whole ecosystems
Ecosystem services	Essential functions of NBS
Agroecology	Subset of NBS, conservation
Semi-natural habitat	A habitat which has been affected directly or indirectly by human activity: hence NBS if it fits one of the NBS activity categories
Management	NBS is a management tool
Sustainable forest management (SFM) Sustainable land management (SLM) Integrated land management (ILM)	Subset of NBS, sustainable practices with long-term mitigation and conservation objectives
Integrated coastal zone management (ICM)	Subset of NBS at landscape scale, can involve green infrastructure, adaptation and ameliorative functions
Sloping Land Agriculture Technology (SALT)	Subset of NBS, sustainable practices and GI technologies
Sustainable and resilient infrastructure	Subset of NBS, broader than GI
Ecological infrastructure	Subset of NBS, using whole ecosystems
Ecological engineering	Subset of NBS, engineering within ecosystems

Generic terms	Interpretation in the framework for NBS in agriculture
Restoring natural flows	Management of water, using natural processes, may be an element of several NBS activity categories
Water harvesting	A subset of soil conservation
Low impact development	Stormwater urban GI
Building with nature	Synonym of GI
Multifunctional systems	Depends on context, can be considered as sustainable practices
Low emission development strategies	Depends on context
Ecosystem based adaptation	NBS to reduce adverse climate impacts
Ecosystem-based disaster risk reduction	NBS for disaster risk reduction
Community based adaptation	Depends on context, can involve NBS to reduce adverse climate impacts
Ecological intensification	Depends on context
Sustainable intensification	Depends on context, can be considered as sustainable practices that reduce agricultural pollutants to soil and waters
Precision agriculture	No defined NBS objective, can be considered as reducing agricultural pollutants to soil and waters
Good Agricultural Practice	No defined NBS objective, can be considered as reducing agricultural pollutants to soil and waters, contributing to improving soil health
Bio-engineering	Broader than NBS and GI: application of principles of biology and the tools of engineering to create usable, tangible, economically viable products
Responsible Investment in Agriculture and Food Systems	Depends on context, can be considered as social benefit of NBS, or a corporate social responsibility (CSR) investment to NBS

Supplementary Table 2. Key NBS-practices in agriculture and their main primary function (++), more and less demonstrated secondary functions (+). A (+) denotes a possibly to select species that contribute to the function.

SUPPLEMENTARY TABLE 2

		NBS typology											Literature r
		Sustainable practices			Green infrastructure			Bioremediation			Conservation		Key references
Demonstrable essential primary function		Must have a productive element			Must have a structural engineering function			Must have a beneficial biochemical, biological or microbial function			Must have a species preservation benefit		*) not found via the se
Generic	Practice	1.1 production	1.2 nutrients	1.3 microclimate	2.1 water flows	2.2 soil erosion	2.3 stabilise slopes	3.1 pollutants	3.2 biota	3.3 carbon sequestration	4.1 biological diversity (field)	4.2 connectivity (landscape)	
Agriculture	Inter-cropping with legumes	+	++										(Iverson et al., 2014)*
Irrigated agriculture	Irrigation systems with smart water management systems	++			+			+				(+)	
Agroforestry	Alley cropping with legumes and/or trees	+	++			++	++			+			(McIvor et al., 2017; W DeLucia, 2018)
	Silvo-pastoral systems for livestock husbandry	+	+	+		+	+			+			(Chandler et al., 2018
	Silvo-arable systems for cultivation; intercropping	++	(+)	+		++	+			++			(Golosov and Belyaev al., 2019)
Silviculture	Reduced impact logging	++				+				+			(Hoque Mozumder et
	Continuous forest cover	++				+	+		+	+	+		(Angelstam and Lazdi
	Native species plantations	+	+	+	+	++		(+)		(+)	(+)	(+)	(Chu et al., 2019)
Aquaculture	Multi-trophic aquaculture	+	++					++					(d'Oultremont and Gu et al., 2019)
Agri-/ Aquaculture	Faunal-aquatic systems	++	+								+		(Mohanty et al., 2009)
Horti-/ Aquaculture	Silvo-aquatic systems	++	+			+						+	(Rahman and Mahmu
Soil conservatio n	Cover crops	(+)	+	+		(+)							(Daryanto et al., 2018
	Contour planting					+							
	Conservation tillage		+			+				+			(Singh et al., 2019)

		NBS typology											Literature r
		Sustainable practices			Green infrastructure			Bioremediation			Conservation		Key references
Demonstrable essential primary function		Must have a productive element			Must have a structural engineering function			Must have a beneficial biochemical, biological or microbial function			Must have a species preservation benefit		*) not found via the se
Generic	Practice	1.1 production	1.2 nutrients	1.3 microclimate	2.1 water flows	2.2 soil erosion	2.3 stabilise slopes	3.1 pollutants	3.2 biota	3.3 carbon sequestration	4.1 biological diversity (field)	4.2 connectivity (landscape)	
	Planted grass strips	(+)	+		+	++		+	(+)				(Are et al., 2018; Huar Lenka et al., 2017; Sir
	Planted brush structures	(+)				++	++		(+)				(Ebabu et al., 2019)
	Trees or shrubs planted principally for soil conservation purposes						++			+	(+)	(+)	
	Hedgerows; live fences	(+)			++				(+)			(+)	(Gatto et al., 2019; Ho
	Terracing made with living plants forming a key structural element	(+)	(+)		(+)	+							(Zuazo et al., 2011)
	Sloping agricultural land technology (SALT)	+			++	++							
	Geotextiles made from straw and bamboo (with contour planting)	+		(+)		+	++						(Bhattacharyya et al.,
	Fallow land with active management interventions		++										
	Mulching; crop residue incorporation		++										(Are et al., 2018)
	Nurse plants in productive plantations			+							+		(Lu et al., 2018)
	Water harvesting systems of collectors, drains, sinks and storage ponds; field trenches; planted pits	++		+	(+)	`(+)							(Mishra and Mohanty,
	Shelterbelts as wind breaks			++				++		+		+	(Xie et al., 2018)

		NBS typology											Literature r
		Sustainable practices			Green infrastructure			Bioremediation			Conservation		Key references
Demonstrable essential primary function		Must have a productive element			Must have a structural engineering function			Must have a beneficial biochemical, biological or microbial function			Must have a species preservation benefit		*) not found via the se
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Soil conservation	Encouraged bioturbation							++					(Hoang et al., 2018)
Amelioration	Phytoremediation of soil conditions	(+)	(+)			(+)		++					(Zhang et al., 2019b)
	Phytoremediation of water quality							++					(Gikas et al., 2018)
	Buffer zones							++				+	(Aguiar Jr et al., 2015; al., 2005)
	Denitrifying bioreactors that use woodchips or other organic processes							++		+			(Hassanpour et al., 20 Burbery, 2018; Woli et
	Pollutant bioremediation							++					(Hassanpour et al., 20 al., 2019; Sharma et a
	Vegetation filter strips / grass buffer strips				+	+		+					(Gene et al., 2019)
	Vegetated drainage ditch				+	+		+					(Vymazal and Březino
Wetlands	Constructed reed beds and cleaning pond systems							++					
	Constructed wetlands							++				+	(Chapman, 2012; Gika Lee et al., 2014)
	Water treatment wetlands							++					
	Riparian wetland management; buffer zones	+			(+)			+				+	(Anbumozhi et al., 200 Mander et al., 2017; W
	Ponds for sediment collection				+								(Mtibaa et al., 2018)
	Vegetated swales				+	++							(Gene et al., 2019)
	Ponds for water treatment							+ +					(Jia et al., 2019)
	Wetlands for ecological diversification											++	

		NBS typology											Literature r
		Sustainable practices			Green infrastructure			Bioremediation			Conservation		Key references
Demonstrable essential primary function		Must have a productive element			Must have a structural engineering function			Must have a beneficial biochemical, biological or microbial function			Must have a species preservation benefit		*) not found via the se
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	Ponds for ecological diversification										+		
	Floodplain designated storage area				++								
	Re-connected / reconstructed floodplain		+					++		+	+		(Schilling et al., 2017; 2011)
	Riparian forest									++	+	+	(Angelstam and Lazdi Turunen et al., 2019)
	Mangrove forest planting	+			++					++			(Dat and Yoshino, 201 Mozumder et al., 2018
Biodiversity conservation	Protected areas									+	++	++	
	Remnant forest / grassland / wetland patches; ecological focus areas									+	++		
	Multifunctional land use with conservation provision	+			++	+				+	++	++	(Mtibaa et al., 2018)
	Wildflower verges or other pollinator habitat	+							++		++		(Ganser et al., 2019)
	Agro-biodiversity: use of varied provenances of seed or livestock	+									++		
	Beneficial predator species introduction (pest control)	++							++		++		(Rosas-Ramos et al., 2

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