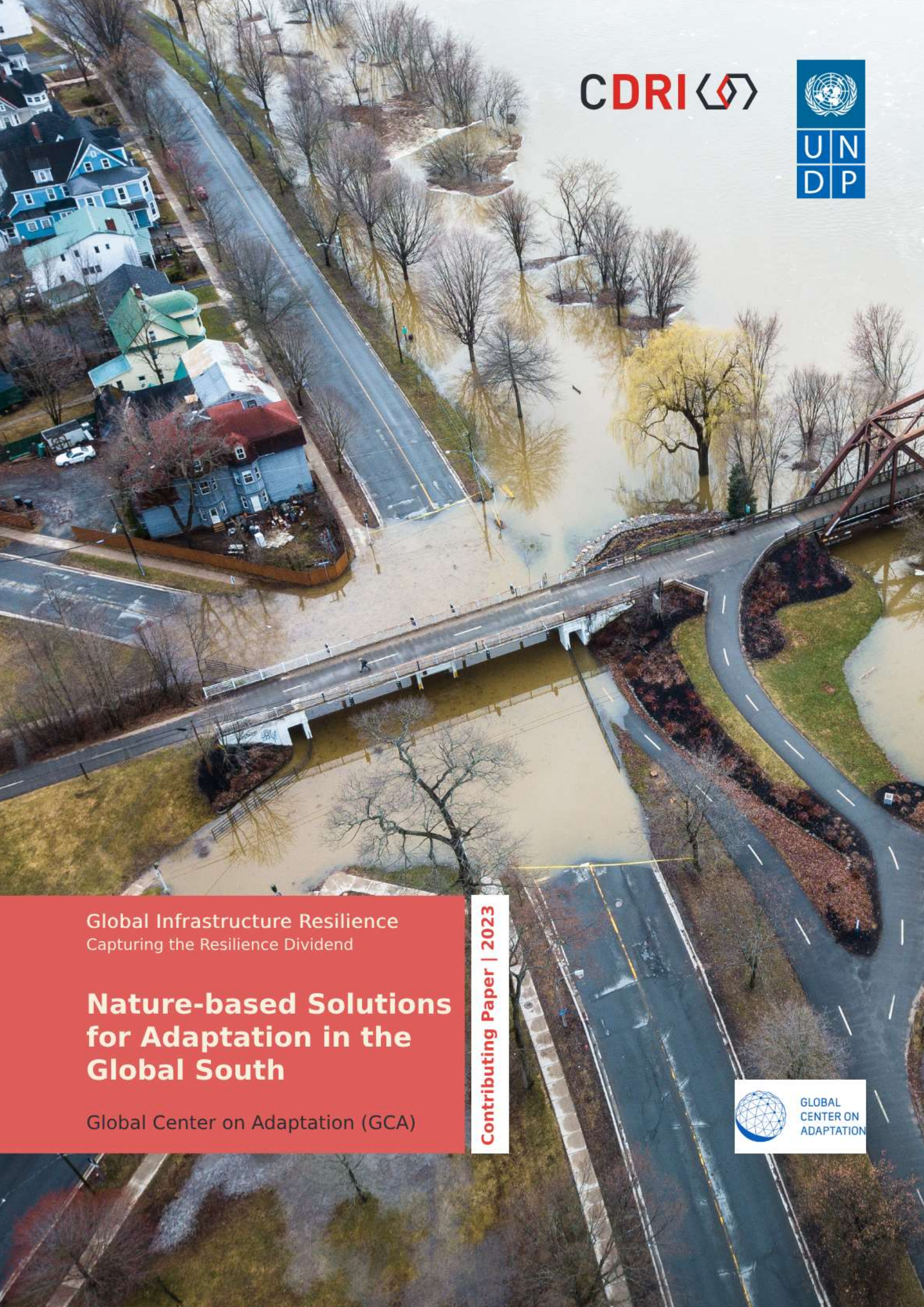

Global Infrastructure Resilience
Capturing the Resilience Dividend

Nature-based Solutions for Adaptation in the Global South

Global Center on Adaptation (GCA)

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Nature based solutions for adaptation in the Global South

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Focus areas: climate risk and adaptation to climate change, infrastructure development, environmental, social and economic co-benefits of NbS, Global South

Definition of infrastructure used by CRDI for the flagship report.
*Infrastructure includes **physical infrastructure** (energy, transportation, water supply, sanitation, and telecommunications) as well as **social infrastructure** (education facilities, health care centers, places of worship and community centers) and **ecological infrastructure** (healthy forests - including mangroves and riparian forests); healthy scrublands (including beach and dune vegetation); healthy grasslands; healthy soil; functioning rivers, floodplains, wetlands and estuaries; and intact beaches and dunes.*

Problem statement: The risk of land-based food insecurity is one of the eight key climate risks identified by the IPCC. Moderate or severe food insecurity affects one quarter of the global population and has been rising in recent years. Over half of the population in Africa, almost one third in Latin America and the Caribbean and more than one-fifth in Asia are food-insecure. The need for wide-spread transformation of agricultural systems is clear, and Nature based Solutions (NbS) can play a key role in a sustainable future of food. NbS are increasingly viewed as a way to reconcile economic development with the stewardship of ecosystem in the Global South. Many NbS projects and initiatives constitute a means to diversify and transform livelihoods and enhance rural resilience, the ability of rural dwellers to preserve welfare in the face of (climate) shock. However, the solutions tend to be poorly connected and fail to provide a cohesive approach towards mainstreaming NbS into planning, financing and implementation. Mainstreaming NbS can provide cost-effective adaptation alternatives to traditional 'grey' solutions for resilient rural infrastructure with environmental, social and economic co-benefits. The comprehensive analysis provided by this paper regarding NbS for feeder roads and water stress, where economic as well as ecological and social needs are considered, builds the evidence base to catalyze adaptation action.

Key messages:

- NbS can play a key role in sustainable and resilient food systems once their adoption is accelerated.
- The use of nature-based solutions in the long term can be encouraged by their inclusion in national plans or strategies like the National Adaptation Plan (NAP) or the Nationally Determined Contributions (NDC).
- Devolution and decentralization of resource management to the community level is important to increase adoption of NbS in rural areas
- Increased knowledge and research on the benefits and costs of NbS is required to create a business case to increase investments.
- Quantifying indirect benefits at the national, community and household level in a full assessment of benefits can inform decision making and increase investments.

1. FOOD SYSTEMS, INFRASTRUCTURE AND CLIMATE CHANGE

The demand for food has escalated in recent decades and is expected to continue growing as global populations increase and economic affluence expands. Farmers and pastoralists depend on this infrastructure to manage their on-farm operations and sell their produce. Feeder roads and other systems for transporting goods, institutions such as those that provide R&D, ICT and financial services, warehouses, water-supply, energy infrastructure as well as waste management are all essential for the functioning of food systems. Farmers have also often installed infrastructure on their farm e.g., soil and water management technologies, agricultural and irrigation equipment, machinery and storage facilities (Turley & Uzsoki, 2018). Furthermore, agricultural production relies on the provision of environmental services such as pest control, pollination, nutrient (re)cycling, soil conservation, structure and fertility, water provision, quality and quantity of carbon sequestration, and biodiversity (Kumar, 2011; Rincón Ruíz et al., 2015). Some of these environmental services are provided by ecosystems such as forests, mangroves, scrublands, grasslands, rivers, floodplains, wetlands, estuaries, beaches and dunes.

The healthiness and functionality of ecosystems is crucial for the continued supply of environmental services. However, lands, soils and water supply are under immense pressure. By the most credible estimates, up to 52% of global agricultural lands are now moderately to severely degraded (FAO et al., 2021). Millions of hectares per year are degrading to the point of abandonment by land managers. The loss of productive land, coupled with increased food demand, pushes agriculture to be the primary driver for 80% of native habitat loss. Additionally, agricultural irrigation is driving the majority of water scarcity issues in high-risk basins threatening food systems, community water supplies and ecosystem health. Recent estimates suggest that between 720 and 811 million people in the world faced hunger in 2020 (FAO et al., 2021); two-thirds of whom live in rural areas. Also, these pressures have resulted in the global agriculture sector driving more biodiversity loss, destruction of natural habitat, soil degradation and depletion of natural resources around the world than any other industry (FAO et al., 2021).

Climate change is expected to further undermine food security (Laborde et al., 2020). Climate change manifests itself through changes in frequency or severity of climate-related hazards, and through gradual shifts away from the (observed) “climate normal”, towards conditions that increasingly fall outside of what people and natural systems are used to (Hawkins et al., 2020). For wheat, rice and maize in tropical and temperate regions, local temperature increases of 2°C or more, above late 20th century levels, will negatively impact production, although individual locations may benefit (Challinor et al., 2014). A temperature rise of 4°C or more, above late 20th century levels, combined with growing food demand, is expected to pose large risks to food security globally. Reductions in maize and wheat yields could reach up to 50% for many countries across sub-Saharan Africa, South Asia, Southeast Asia and Latin America (IPCC, 2022). Additionally, extreme weather events such as reduced rainfall, high temperatures, prolonged dryness and higher frequency of heavy rainfall events threaten water provision, soil quality, as well as plot and market access. Reduced rainfall is likely to reduce surface water flows and groundwater recharge. More frequent heavy rainfall events are likely to augment the risk of flooding as well as increased sediment and nutrient deposition into surface water bodies. In addition, prolonged dryness and increased water temperatures will affect surface water quality (Peng et al., 2021). Pollutant concentrations will rise while higher water temperatures encourage algal blooms and increase risks from cyanotoxins and natural organic matter in surface water bodies (Delpla et al., 2009; Whitehead et al., 2009). These in return will affect the soil quality. Extreme weather events such as floods, by affecting agricultural production or making roads impassable, are already compromising the livelihoods of rural dwellers (IPCC, 2022).

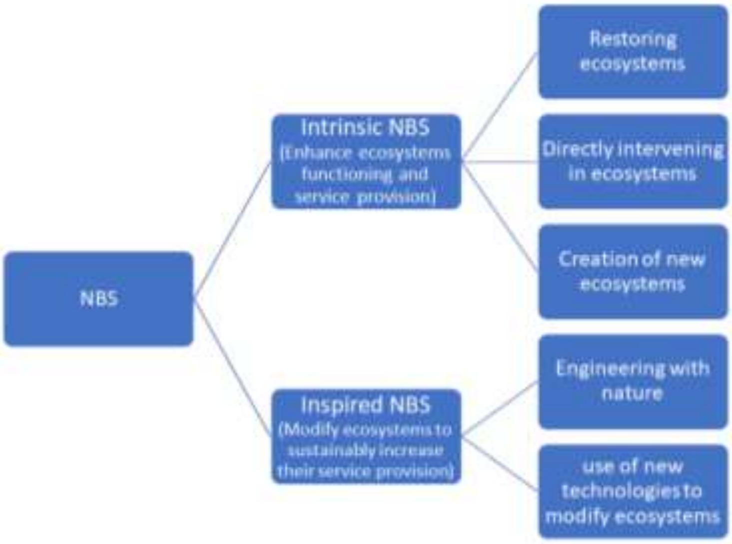
To sustain the future of food systems – and by extension, human life – agriculture producers around the globe must lead a transition to agricultural practices that regenerate landscapes. Nature based solutions - interventions that recalibrate development and address risk drivers including climate change – are a promising strategy to do so. This position paper discusses the potential of NbS to enhance resilience in the Global South and provides guidelines to leverage this potential. It first introduces the priority intervention areas for rural resilience, then reviews the co-benefits of the NbS when these priority areas are concerned. It then presents the key layers of information required for facilitating NbS. The paper then delves into the question of economics and discusses the benefits of a potential economic model when discussing the monetary benefits with respect to ecological and social ones. The paper concludes with guidelines for decision-makers and practitioners for local adaptation and resilience action prioritization, and main takeaways for policy, planning and action.

2. PRIORITY INTERVENTION AREAS FOR NBS TO CONTRIBUTE TO RURAL RESILIENCE

Nature based solutions defined by UNEA (The United Nations Environment Assembly) as 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits' have the potential to play an important role in the functioning of food systems under climate change.

Two types of NbS have been distinguished with respect to their impact (Cohen-Shacham et al., 2016; Somarakis et al., 2019) (see Figure 1). Intrinsic NbS (type 1) focus on enhancing the function of ecosystems and the respective service provision (e.g., agro-forestry, intercropping). Inspired NbS (type 2) are based on the modification of ecosystems to ensure the sustainable increase of the related service provision (e.g., slow sand filtration and biofiltration for biological disinfection of wastewater). Both types present a wide range of possibilities to enhance food system resilience.

Figure 1. NbS categorization



While the existing literature has the tendency to predominantly discuss intrinsic landscape-based NbS (e.g., agro-forestry, ecosystem restoration), inspired NbS add value addressing food systems challenges in areas where land is a scarce resource. Both constitute alternatives or complements to traditional grey infrastructure solutions in addressing climate change and environmental services provision.

2.1 NbS to tackle water stress and enhance soil quality

Depending on the geography (e.g., tropics, subtropics and mid-latitudes), a changing climate may lead to water stress and reduced soil quality. Adaptation in these contexts would mean maintaining or increasing flows in surface and groundwater bodies or tackling the risk of flooding and sediment and nutrient deposition into surface water bodies (IPCC, 2022). NbS can act as a regulator of water flows, reduce soil erosion and retain nutrients on the land (Thorn et al., 2021). These solutions can be applied in upstream areas to protect river sources and benefit downstream users (Acreman et al., 2021). Downstream users mostly include farmers, water utility companies and hydropower generation. Reforestation of degraded lands, terracing of steep farmlands are classified as intrinsic NbS examples that can restore or create ecosystems. In addition to increased carbon sequestration and local climate regulation (Kumar et al., 2021; Sy et al., 2014), intrinsic NbS may offer multiple water-related benefits through reducing the risk of flooding at riverbanks and floodplain areas (Ozment et al., 2021).

Riparian buffers, for example, protect both water and soil. A riparian forest usually surrounds a body of water to create a natural filter for the water (Dosskey et al., 2010). The area is zoned for different vegetative growth, which often contains forestry (Daigneault et al., 2016). The plants and supported soil act to prevent an accumulation of agricultural chemicals in the water source (IFAD, 2021). The riparian buffer also serves to minimize erosion, ensure more even water drainage and decrease the impact of adjacent agricultural uses (Flores et al., 2019). It may also serve as a wildlife corridor, increase plant and animal diversity by ensuring access to clean water and allowing natural vegetative growth. Another intrinsic form of NbS are shelterbelts. Shelterbelts are trees planted to protect agriculture from extreme weather. The trees minimize the effects of strong winds and rainfalls that cause erosion to crops (Smith et al., 2021). Trees also provide protection for wildlife, which in turn creates and fosters biodiversity. Ultimately, shelterbelts help to mitigate the effects of extreme weather while also allowing for carbon sequestration and improve crop yields. For millennia African farmers have been using NbS on their farms, without calling them as such. They have been using measures such as grass strips, stone bunds and planting pits to sustainably make use of the soil and landscape resources. These techniques capture water and sediment from upstream and enhance soil quality (Keesstra et al., 2018).

Individually these measures are not sufficient to come to sustainable landscape management, however when all farmers in an area implement these techniques there is a strong potential to enhance soil quality. An example from the American Dust Bowl of the 1930s underlines this. The prevalence of small farms limited private solutions for controlling the downwind externalities associated with wind erosion. Drifting sand from unprotected fields damaged neighboring farms. Small farmers cultivated more of their land and were less likely to invest in erosion control than larger farmers. Soil conservation districts, established by the government after 1937, helped coordinate erosion control. This “unitized” solution for collective action is similar to that used in other natural resource/environmental settings (Hansen and Libecap, 2004).

Both riparian buffers and shelterbelts are pre-production infrastructure interventions that protect water quality and soil quality in the face of extreme weather conditions and changes. Wind and flood damage can be mitigated by building these infrastructure projects into agricultural plans. Moreover, it helps to restore natural ecosystems, which are naturally more resilient to climate change. In addition to the intrinsic ones, inspired NbS solutions such as engineering with nature and the use of new technologies to modify ecosystems may combine ecological and recreational objectives to provide ecosystem services. Stabilization infrastructure is an alternative to riparian buffers. Stabilization infrastructure consists of a human-made structure that controls the grade of the land by creating artificial barriers, steps and channels between the agricultural activity and the body of water. These structures can reduce erosion that negatively affects water quality (Aerts, 2018). Farm operators can also build retention ponds to keep rain and storm water during periods of increased precipitation (Ruangpan et al., 2020). Diversion channels may also help to control water source distance to agricultural activities that could also minimize negative impacts on water quality. On a more macro scale, climate resilient water management is a key component in creating sustainable agribusiness (Acreman et al., 2021). Water management is critical especially as it relates to floods and droughts as these extreme events create significant impacts on the agri-food business.

2.2 NBS to protect feeder roads

Flood prone areas, including transportation corridors, are particularly exposed to deterioration or destruction due to extreme weather events. At lower altitudes, transportation corridors suffer from flooding during storms or the rainy season. Constant flooding makes roads susceptible to damage. Even with constant maintenance, the road structure may deteriorate faster compared to an area that is less exposed. In comparison to a complex traditional engineering approach, NbS may constitute a solution with additional benefits (Kim et al., 2022). Similar to the riparian forest, a belt with plants or green areas has the capacity to capture the excess water from the road. Other NbS solutions are green zones alongside the road, reservoirs to keep water from flooding, reforestation for landslide control or storing of water for the dry season (Amollo & Bosma, 2019). At higher altitudes, specifically in mountain regions, landslides are common problems to tackle in the context of climate adaptation and resilience. Rainy season landslides in the upper watershed can cover roads, disrupting the transportation of foods to markets. Replanting steep hillsides adjacent to slope roads with forest (Grima et al., 2020), and potential other vegetation is useful to control landslides, creating a root system “net” over the surface of the hill (Kim et al., 2022).

Case Study 1: The Haor Infrastructure and Livelihood Improvement Project (HILIP) and Climate Adaptation and Livelihood Protection (CALIP)

The Haor Infrastructure and Livelihood Improvement Project (HILIP) and Climate Adaptation and Livelihood Protection (CALIP) focus on reducing the vulnerability of people in the Haor basin, a wetland located in North-Eastern Bangladesh (Kamruzzaman & Shaw, 2020). During the monsoon season, the region gets between 3,000 to 4,000 mm of rainfall, causing the Hoar to be flooded 4-8 meters for six months a year (IFAD, 2019). The situation is expected to worsen as pre-monsoon rainfall is predicted to coincide with the paddy rice pre-harvest period (IFAD, 2019). Furthermore, embankments, riverbanks and other hydraulic structures that act as defense mechanisms against storm surges and flooding are vulnerable to erosion. The project will be implemented in 28 Haor Upazilas of five districts: Kishoreganj, Netrakona, Sunamganj, Habiganj and Brahmanbaria. It intends to support 688,000 households, consisting mainly of smallholder farmers, small fishing households, poor female headed households, and traders and market intermediaries in local markets. As part of the CALIP project, vetiver was introduced and planted across the landscape to create natural wave barriers and generate carbon sequestration benefits (IFAD, 2020). It is expected that 50 kilometers of roads built by HILIP will be protected with vetiver grass. Additionally, to improve navigation and water-carrying capacity, canals and beels (lake-like wetlands with static water) are excavated (ASAP, 2014). As part of CALIP, the use of vegetation to

Case study 2: Coastal Climate Resilient Infrastructure Project

The Coastal Climate Resilient Infrastructure Project (CCRIP) in Bangladesh aimed to increase resilience of the food system by investing in flood-resilient roads and infrastructure, community markets, and climate preparedness capacity. The cost of the project was US$150 million, jointly funded by IFAD, Asian Development Bank, the German Development Bank and the Government of Bangladesh (Arslan et al., 2019). The aim of the project was to reach 600,000 households from 32 Upazilas across 12 coastal districts in the country (Arslan et al., 2019). By the end of the project, over 5.7 million people benefitted from the infrastructure supported by the project. Cumulatively, 750 km of roads and 5,315 m of bridges and culverts were constructed (One Planet Network, 2021). A key component of the project was to hire Labour Contracting Societies (LCS). LCSs mainly consisted of poor women, who carried out some of the construction work (Arslan et al., 2019). The intervention provided 69,300 workdays among 5,723 people contracted to LCS, of which 79% were women (One Planet Network, 2021). To prevent flooding, community markets were improved by installing raised areas and drainage systems. The roads were stabilized using vetiver grass as part of the climate sensitive measures. Furthermore, the project aimed to provide facilities such as storage and processing facilities, river docks and a section for

Case study 3: Bono East

The Bono East region is the food basket of Ghana. A large part of Ghana's food is produced there, ensuring national food security. However, the region is extremely vulnerable to periodic water shortage as climate change leads to variable rainfall and unpredictable times of drought and floods. Forest and landscape restoration (FLR) can be a solution for declining soil fertility and water shortage. FLR is a planned process to tackle deforested or degraded landscapes by focusing on ecological integrity and enhancing human wellbeing (IUCN, 2022). FLR is already being practiced by farmers or is being introduced by the Ghana Forestry Commission. The three main FLR approaches for food are

1. Modified Taungya System, which allows for multifunctional land use. In this system, farmers are given a degraded area of state-owned forest land where they plant trees and crops (Oosten et al., 2022). The aim of the system is to maximize the complementarities between the forest (shade), the food crops (food security), and the cattle ranges (manure and income).
2. Community-based forest rehabilitation, sustainable farming models of producing crops in forest reserves and trees that are drought resistant on farmland. Most of the reforestation projects are organized by the Youth in Afforestation program under the Youth Employment Agency.
3. Cocoa-based agroforestry. Cocoa grows better in shade, which means that cocoa farming can be combined with reforestation (Oosten et al., 2022). In cocoa agroforestry systems, trees provide timber and shade for the cocoa, as well as nutrients and soil protection for food production. This integrated system enhances climate resilience and increases farmers' incomes. (Oosten et al., 2022).

Several challenges have been identified with FLR, including farmers lack of motivation to plant trees. While farmers are aware of the growing impact of climate change, their first concern is to maintain their food security under these changing conditions. Therefore, while they see the value of planting trees, it is not their main priority. They would rather invest in drought resistant crops or purchase water pumps, not in purchasing seedlings, unless they directly contribute to food security. Additional issues relate to the low access and ownership of farmers to resources such as land and trees, as well as the institutional challenges that are related

3. KEY AREAS OF CONCERN FOR FACILITATING NBS

In this section, we present a framework (see Figure 2) to support the utilization of the above described NbS at scale, including a sequence of steps that would support the scaling. The framework starts from goal identification, to strategy development and potential outcomes. For each of these elements, four layers of information are considered important.

Figure 2: NbS framework

Layers	Scale up NBS infrastructure in rural areas		Food security Disaster risk reduction	Time as an important factor
Knowledge	Awareness of the benefits of NBS	Capacity building Research	Green jobs Innovation Ecosystem preservation	NBS takes time but the benefits are in the long term
Policy	Regulation about NBS Policy push	Norms requiring environmental scope NBS in long term planning	Resilient infrastructure Trustiness in NBS Resilient economy	Adjust the time factor in plans and projects
Governance	Benefits rules usage Appropriation of the intervention Cultural and environmental appropriate intervention	Community engagement Gender perspective Land ownership	Increase of social capital Equitable rural development	Dynamic and frequent evaluation
Finance	Long term funding Monetizable benefits	Blended finance Integration of NBS with traditional infrastructure	Unlock investment Innovation in finance instruments	Continuous monitor and evaluation to enhance trust

3.1 Knowledge

Akin to most adaptation solutions, NbS will be identified and implemented at the local level. As a result, it involves the interdependence of agents through their relationship with each other, the institution in which they reside and with the resource base on which they depend. It requires a joint effort by the community, stakeholders, and policymakers to trust and care for the ecological infrastructure (Dolisca et al., 2006).

To help stakeholders identify where action is needed the most, vulnerability assessments and local climate projections can help formulate a clear climate rationale. In the absence of official sources of data, mixed methodologies for data collection are required or a model design that is able to be adjusted. Thus, evidence-based research/knowledge establishes a realistic basis for implementation that is informed by place specific gender dynamics, economic, social and environmental assets.

Some NbS seem to be less effective when compared to grey infrastructure, making stakeholders less inclined to invest, even when longer-term benefits may be greater (Seddon et al., 2020). Therefore, scientific knowledge should be packaged in a comprehensible manner and disseminated to the broader public, among different stakeholders. It will help reduce transaction and information costs and involve the public and private sector in identifying vulnerabilities as well as adaptation solutions. Knowledge in communities could increase the awareness of the importance to preserve the ecosystem as well as of the effectiveness of the measure and its benefits. For example, knowledge of farm management is a first step to familiarize a farmer with NbS, which may have been used in the past or in another context (Kandel et al., 2022).

3.2 Planning and policy

The inclusion of NbS in national plans or strategies like the National Adaptation Plan (NAP) or the National Determined Contributions (NDC) propose the use of nature-based solutions for the long term (Ozment et al., 2021). Like other policies and plans, the success in the implementation and maintenance relies on a continuous follow up in the development and responses (Nelson et al., 2020). Thus, NbS faces a similar challenge to other adaptation solutions, which is that proper planning is required to avoid maladaptation (Oakes et al., 2021; Seddon et al., 2019). However, being a relatively new infrastructural technology, the norms and regulation for the implementation and planning procedures and processes are not clearly defined. Coupled with the development of a clear regulatory framework, norms encouraging the review of NbS or a mix with grey infrastructure alternatives, for disaster risk reduction or economic improvement, increase the likelihood of implementation (Ozment et al., 2021). In addition, NbS should be embedded within the institutional system so that it can be mainstreamed and upscaled.

Local action (for advancing adaptation) is a combination of complementary interventions undertaken by government, development partners, civil society organizations, and private sector groups that explicitly aim to support households, communities, and/or local governments as they adapt to the adverse impacts of climate change and strengthen resilience. These interventions can be designed at any level—national, subnational, or local—but are implemented at the local level in close consultation with local stakeholders. Data collection, analysis, planning and policy development can also be empowering. Involvement of communities in data gathering, and GIS mapping can help them to understand and articulate their needs and challenges better, and to negotiate more effectively with governments.

3.3 Governance

Strong local support for NbS is key to success (Hou-Jones et al., 2021). One reason for this is that locally-led NbS enhances social capital in the community through the continuous interaction towards a common goal (Chausson et al., 2020). Locally-led adaptation also ensures community ownership in the long-run, as it encompasses related negotiations and consensus building on the exploitation of benefits and profits among actors (Bridges et al., 2021; IFAD, 2021; Ozment et al., 2021; Wijsman & Berbés-Blázquez, 2022). This supports the effectiveness of adaptation action by creating a common understanding of the options for adaptation, institutional constraints against the implementation, and their role in the wider landscape of economic development and social evolution.

People who derive their livelihood from farming influence and receive benefits from the goods and services that ecosystems provide and are often important custodians with customary roles and distinct roles in local industry. Given the cultural history and societal gender roles in local communities, men and women both depend upon and interact with their natural environment for food, shelter, extracted resources etc. in different and often complex ways. These are important considerations when developing and implementing NbS, particularly if it implies changes to livelihoods or access to resources. Equitable opportunities to build awareness of both men and women, understanding their societal roles and active participation and leadership in adaptation and resilience themes, from communities to policy makers, is an important part of effective NbS, including efforts that aim to ensure the effective future placement and regulation of managed areas and networks.

3.4 Finance

The sustained scaling of NbS is very much dependent on attracting investments (Ozment et al 2021). The economic case for investing in climate adaptation is strong. Benefit-cost ratios range from 2:1 to 10:1. While some NbS, such as sustainable soil and land management options and improving water efficiency are low regret options with high-benefit to cost-ratios in the short term, major investments will be needed in the medium term and beyond, as these low-regret actions do not deliver more transformational adaptation. Aggregation of adaptation costs that were communicated in the most recent Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) shows that the 76 developing countries will require around 73 billion USD (in current price) per year on average until 2030 to implement their adaptation plans.

Climate finance is thus critical to accelerating climate adaptation and resilience in the Global South. Yet, money is not flowing at the pace or scale needed. At COP26 in Glasgow last year, the global donor community promised to double finance for adaptation from the current rate of up to a quarter of climate financial flows earmarked for the developing world. However, committed funds have fallen short. Countries across the South Asia region have a strong track record in domestic financing for climate adaptation and building resilience into cross-sectoral and financial planning. But, while private climate finance comprises half of total climate finance globally, in Africa it is only 14%. Actual risk, perceived risk, and ticket sizes dissuade private capital players, but several steps could be taken to expand investment. Development partners could target higher leverage ratios through blended financing structures, with a particular focus on an enhanced role for private insurance and partial guarantees. Blended finance is an approach that involves the use of public and philanthropic funds to change the risk/return profile of investment projects in order to attract the private sector. They could also support capacity building, both within domestic finance institutions and in developing a pipeline of investable opportunities.

The Africa Adaptation Acceleration Program (AAAP) led by the Global Center on Adaptation and the African Development Bank aims to mobilize $25 billion to scale up and accelerate climate change adaptation actions across Africa. The AAAP will support countries to make a transformational shift in their development pathways by putting climate adaptation and resilience at the center of their critical growth oriented and inclusive policies. The infrastructure pillar of the AAAP will leverage the project pipelines of multilateral development banks (MDBs) to mainstream adaptation, including NbS, into investment projects, particularly traditional ‘grey’ infrastructure projects. In some cities, urban infrastructure is being readied to withstand flash floods, extreme heat and other climate impacts. Similarly, under the Climate Smart Digital Technologies for Agriculture and Food Security pillar, investments in projects that are making the livelihoods of farming communities more secure have been realized. It does so by improving the accuracy of weather forecasts and making data available to farmers via mobile apps and providing drought-resistant crop varieties in regions where water is increasingly scarce or rainfall unreliable.

The public good nature of many NbS - goods produced are both non-excludable and non-rivalrous - means that costs of, for example, construction, are borne by the implementer while benefits are also derived by a third-party that has not contributed to construction. For instance, a waterboard that pays for the development with respect to flood adaptation through establishment of widened riverbeds allowing the river to connect with the floodplain.[1] The direct beneficiaries are the citizens and companies that are protected from floods and whom contribute directly via waterboard taxes. However, such developments may also foster recreation and companies in this sector, such as waterside restaurants, may benefit while they have not borne any costs. At the same time, farmers may benefit from increased annual yields as effects of flood risks on crop production are reduced

[1]A waterboard is a public commission charged with overseeing water quality in a particular area.

although not directly contributing to the project itself. If it was clear from onset that there were benefits to be derived by third parties, these entities too may be willing to financially contribute to NbS related projects. For instance, shop owners may expect increased revenues which creates an incentive to contribute while farmers realize that flood risk reduction leads to increased yields and thus higher income. Co-financing of NbS by the private sector also de-risks their business (e.g., flood risks for farmers).

Nonetheless, the co-financing of NbS by the private sector is not yet a common practice. While the ecological benefits of NbS are relatively clearcut, the economic ones are much less so. Developing NbS metrics and monitoring their evolution in the long run is important to attract finance for investment (Dolisca et al., 2006; Ozment et al., 2021; Ruckelshaus et al., 2022). The capture of these benefits would need to be accompanied by the development of mechanisms like payments, permits, certification schemes, etc. (Ruckelshaus et al., 2022).

Case Study: The Weija Dam

The Weija Dam is an important water source for sanitation, sustained agricultural production and food security in the Greater Accra Region of Ghana. The Weija dam supplies 80% of potable water for Accra's metropolitan area. Additionally, the catchment supports cocoa production of 11,000 tons per year across 37,000 ha. The dam is susceptible to flooding, affecting its 115 million m3 capacity, and threatening the water supply and safety of communities along the dam. To drive investments that could make the dam more resilient, the costs and benefits of upstream NBS investments in cocoa farming are currently being assessed and a transaction model will be created showing the financial and economic returns on investments, and environmental co-benefits. The aim is to provide evidence to public and private stakeholders of the need and feasibility to scale up NBS. The focus of the analysis are natural flood adaptation measures through greening and vegetation along the Densu River. Potential NBS include restoration of natural vegetation as well as extending tree and vegetation buffers. In turn, these initiatives act as flood control mechanisms. Reforesting in the Weija Reservoir and Atewa Forest will provide shade for the cocoa farms, creating a better microclimate regulation, leading to more consistent yields and higher net cash flow. It is expected that cocoa production will increase 12% ($17 million) if NBS is implemented upstream. Introducing NBS will also increase the water production in Accra. Implementing conservation measures in the Atewa Forest and downstream infrastructure, will reduce sedimentation and improve catchment health. A reduction in sedimentation rates, will ensure long-term reservoir capacity and reduce water production costs. Furthermore, NBS in the Weija Dam could increase water availability for agriculture by 32% and drinking water to 97%, providing water for one million people.

The Weija Dam NBS investment model has the potential to be scaled up for the West African cocoa belt. The cocoa belt supplies 70% of the world's cocoa, which originates from Ghana, Ivory Coast, Cameroon and Nigeria. Once the model has been refined, it could be linked with upcoming and existing investments. An example is the World Bank's Cocoa Integrated Value Chain Development Project. Both the governments in Ghana and Cote d'Ivoire made a request to the World Bank Group (WBG) and African Development Bank (AfDB) to develop an action plan that ensures the sustainability of their cocoa sectors and increases economic and social development (The World Bank, 2019). This request was accepted, and the WBG, with possible support from AfDB, will assess the cocoa sector and identify avenues to influence world market prices (The World Bank, 2019). The project will provide critical resources to accelerate implementation of joint public and private funding. If successful, other value chains such as shea and coffee could also be scaled up using this investment model as an example.

4.1 Valuation of NbS benefits when data are sparse

Cost-benefit analysis can be used to value NbS. A valuation exercise that measures all the ecological production functions may assess most of the benefits in a dynamic form (Gray et al., 2019). These production functions involve the provision of environmental services. This means cost benefit analysis requires a review of multiple options in order to deliver the best solution with respect to culture, society, local economy and the landscape. Environmental services are divided into supporting services, provisioning services, regulation services and cultural services. Several monetization methods exist for these services with market and non-market alternatives like residual prices, hedonic prices, replacement cost, avoided damage cost and opportunity cost (Bockarjova & Botzen, 2017; Rincón Ruíz et al., 2015; United Nations et al., 2021). All have direct and indirect use values, and option non-use values (Hein et al., 2006). However, the scope of these services is rather diverse. The UN's System of Environmental Economic Accounting (SEEA) explains how to measure the environmental services provided by ecosystems in a systematic manner (United Nations et al., 2021), and defines the accounting of the environmental services provided by each ecosystem. Assessing the physical units and a subsequent monetary valuation are the main elements of this measurement. Double counting remains a challenge given that an environmental service could be provided by the chain of multiple environmental goods (Hein et al., 2006). Pollination provided by the bees attracted by trees in cropland is an example to this. As opposed to direct benefits from grey infrastructure, benefits of NbS probably take longer to realize (e.g., time for a forest to grow or be restored). Second, the benefits of NbS increase if we consider that the impacts of climate change are becoming more severe over time. It is important to note that the uncertainties concerning the benefits of NbS also increase as the scenarios of climate change become more uncertain. A solution to deal with high uncertainty in cost benefit analysis is to compute using high discount rates and to minimize the time horizon of the project over which the costs and benefits are calculated. Yet, doing so will lead to an under-estimation of benefits of NbS and does not do justice to the high value of NbS in the more distant future.

4.2 Decision making of private actors

Making adaptation decisions can be complex, requiring careful consideration of multiple factors and perspectives, and balancing different priorities over different timescales. Societies are said to only be at the start of a learning process that will continue for decades (Conway 2011). Decisions on adaptation are made by individuals, groups within society, organizations and governments on behalf of society. But all decisions privilege a set of interests over another and create winners and losers.

The millions of small-scale producers are vital to global food security. Climate change is slated to affect yields and while farmers are in the habit of adjusting their production practices to variable weather conditions, they have not done so at the scale and speed currently required. Adoption of NbS by smallholders will be vital to build rural resilience and enhance food security. In general terms, we view or model an individual as a collection of decision rules (rules that dictate the action to be taken in given situations) and a set of preferences used to evaluate the outcomes arising from particular situation-action combinations. In this case, uncertainty means that outcomes cannot be known for certain and the farmer would have to attach a probability to each. Socio-economic factors such as size and composition of the farm household and asset holdings influence decision-making. At the same time, barriers such as access to finance may prevent farmers from carrying out their decisions. In a recent study, Wouterse et al. (2022), has amended a farm household model to make inferences on drivers of adoption of adaptive production strategies.

The costs and benefits of NbS influence the decision making of farmers and pastoralists but social capital is also likely to be an important factor in decision making. Many adaptation interventions, such as enhancing the resilience of infrastructure or providing common resources without clearly enforceable property rights as for example biodiversity, have traits of a public good and their benefits are expected to accrue over a longer time horizon (Conway, 2011). Collective action is at the heart of many decisions on the management of natural resources. In agriculture, forest and other resource dependent livelihoods, resources frequently exist under multiple property rights regimes. There are many different users, and there is limited information about the impacts of environmental change on sustainability. Diverse social sciences have explored how societies choose to allocate scarce resources in the face of limited information and uncertain futures. Common to all theories of social interactions is the recognition that collective action requires networks and flows of information between individuals and groups to oil the wheels of decision-making.

4.3 NbS and the macroeconomy

Zooming out, the aggregate appraisal of the benefits at the country level means assessing the impact of NbS investments on employment, poverty reduction, GDP and other macroeconomic variables. Countries in the Global South are acutely aware of the importance of climate change for development (Collier et al., 2008; World Bank, 2016). Governments are concerned that unmitigated climate change will hit poor people particularly hard and may put development achievements at risk. Nature based solutions do carry the potential of a triple dividend avoiding future losses, generating positive economic gains through innovation and delivering additional social and environmental benefits (Global Commission on Adaptation, 2019).

For example, the implementation of NbS reduces future damages to infrastructure due to climate change. More resilient roads would allow farmers to continue to reach markets (with indirect effects on inflation). The creation of adaptation jobs such as maintenance of NbS would reduce un- or under employment that is so pervasive in many rural areas of the Global South. Reforested areas would increase the possibility to offer offsets to mitigate emissions from other economic activities. Of course, there are trade-offs and losses associated with NbS. For example, an increase in the area under forests by diminishing the area under crop cultivation could seriously affect agriculture value added due to the reduction in agricultural production. Also, poorly managed NbS could become a fiscal burden for the country in the long run. However, when we account for other benefits of NbS such as the provision of environmental services, trade-offs may be less stark (Banerjee et al., 2021). In summary, to mainstream NbS into decision making, a comprehensive analysis is required that allows for the interaction between variables and their economy-wide implications.

5. CONCLUSION: GUIDELINES FOR LOCAL ADAPTATION–ACTION PRIORITIZATION IN THE GLOBAL SOUTH

This paper has demonstrated that nature-based solutions such as riparian buffers and/or shelterbelts are effectively supporting the agricultural production and food security in tackling water stress and enhancing soil quality. Ecological solutions like replanting or greenbelts also serve as cost-efficient alternatives to large-scale traditional infrastructure investments when protecting the feeder roads. Nonetheless, the adoption of nature-based solutions by the public and private sector as well as the civil society is still at an infant stage. Respectively, the paper defined the main areas of concern and action – namely, knowledge, policy, governance and finance – to help support the mainstreaming of the respective NbS in the rural Global South. With the argument that, to make NbS work, action in all these areas should incorporate the articulation of NbS as an investment case for public and private stakeholders with financial returns on investments, the paper then defines strategies to reveal the underlying economics of NbS.

This final section, as a synthesis, focuses on a framework of action to expand the scope of use, specifically to accelerate adaptation and resilience in rural areas of the Global South. To do so, knowledge, policy, governance and finance gaps need to be addressed. The quality of the enabling environment and institutional capacities are significant factors of success. Achieving high levels of coordination in governance requires the engagement of various stakeholders at different levels. Networks and flows of information between individuals and groups are important to oil the wheels of decision-making.

The above discussion has demonstrated the potential of NbS to enhance rural resilience in the Global South. To leverage that potential and enable NbS to scale from their current pilot phase, several knowledge building blocks would need to be in place. These are detailed below:

i) ***Climate risk to natural assets assessments at a local level***

There is a need to supplement well-known global-scale assessments of climate hazards and vulnerabilities with a sub-national level vulnerability analysis to guide local action. In fact, sub-national vulnerabilities constitute a missing link between large-scale assessments and the required processes for planning and priority setting within countries. Micro-regions are smaller administrative areas within a country. And a typology – systematic classification of types according to their common characteristics – of such smaller areas has been used for priority setting by policy makers. This will, for example, allow for the prioritization of areas with high population density or those that are important to food production. Vulnerability to climate risk is determined by biophysical as well as socio-economic factors. Assessing vulnerability also from the latter perspective would add an extra layer of information to any targeting or prioritization process.

ii) Ecosystem services impact assessment

Nature's ecosystem services are not yet fully recognized in the economy. One reason for this is that they are very diverse. For example, there is the provision of raw materials, the avoided damages by using sustainable practices and the reduction of climate risk. An assessment of provision of ecosystem services at a local level under development scenarios forecasts future deficits in environmental services, even with possible scarcity scenarios. An overlay of areas identified through the first step points to locations where NbS is a win-win strategy reducing the climate risk and providing ecosystem services. As seen before, the interaction between climate and ecosystem use sends alerts about the urgency of an intervention to enhance rural activities. In order to retrieve those alerts, it is necessary to have a systematic review of the relation between climate and environment.

iii) *Cost-benefit analysis of NbS to address climate risk*

The choice between NbS and grey infrastructure relies on a valuation of costs and benefits of each with the best available information. Nature based solutions have benefits that are typically not quantified in the decision-making process of adaptation. A close-up scan of the target area provides an accurate assessment of the cost of a green intervention. Zooming in on the subregional level, for example, would help to define the set of context appropriate NbS interventions. Furthermore, this is a great opportunity to start the engagement with the community, recognizing the social and economic particularities of the territory and evaluating the possible trust in the intervention. Neglecting the local context would lead to the underestimation/overestimation of costs of the intervention and could result in maladapted designs and/or a lack of buy in of the community.

The assessment of benefits, in addition to incorporating non-economic aspects, also needs to incorporate a temporal aspect. NbS require more time for their establishment. Instead of presenting a problem for green infrastructure, the incorporation of the benefits over time opens the door to innovative funding. For example, low-cost infrastructure with returns in each period is attractive for investors. This attractiveness facilitates the funding of the project from non-public sources, alleviating the burden to the public budget.

iv) *Developing the investment case for NbS:*

Assessment of pilot NbS and documenting factors contributing to their success could help assure funding for similar initiatives elsewhere in the long term. These learnings in combination with steps i) to iii) would ensure the preparation of pipeline of context appropriate NbS with high potential to enhance resilience of rural communities and present a solid investment opportunity.

There is a need to adopt the above guidelines for investment and action. Collective action, the conjunction between a thoughtful policy and institutional engagement, defines the full support from the government in the scale up of any adaptation strategy, especially NbS. Ex-ante engagement in an enabling environment in the initial stages guarantees the gathering of relevant information. Pertinent information guarantees that interventions fit with the environment and the beneficiaries have a complete assessment of cost, benefits and risks. Modelling indirect benefits at the macro and micro level facilitates the full assessment of the benefits from NbS. More information about the benefits leads to better decision making and policy design and can ensure the enhanced well-being of the society.

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