UN environment programme

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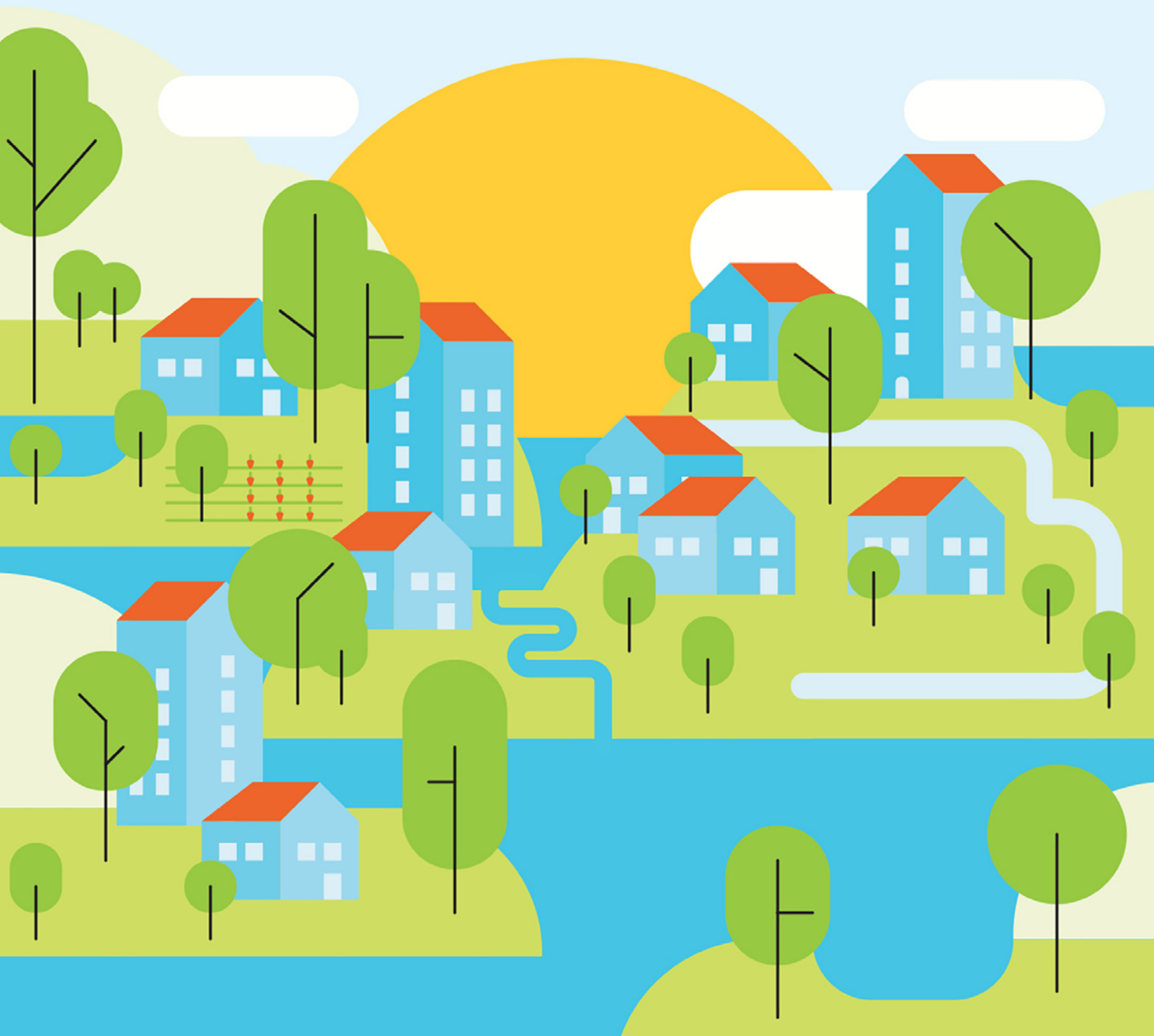
Oxford Infrastructure Analytics

UNIVERSITY OF OXFORD

NATURE-BASED INFRASTRUCTURE

How natural infrastructure solutions can address sustainable development challenges and the triple planetary crisis



Suggested citation: United Nations Environment Programme (2023). *Nature-based Infrastructure: How natural infrastructure solutions can address sustainable development challenges and the triple planetary crisis*. Geneva.

ISBN: 978-92-807-4099-8
Job number: DTI/2590/GE
DOI: *https: //doi.org/10.59117/20.500.11822/44022*

Acknowledgements

UNEP, UNOPS and the University of Oxford would like to express gratitude to the following individuals and institutions. The report benefited greatly from their expertise and contributions as authors and peer reviewers.

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UNEP gratefully acknowledges financial support from the Swiss Federal Office for the Environment (FOEN).

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Definitions

There are several terms that are used consistently in the context of sustainable infrastructure development and nature-based infrastructure development. The definitions below describe how these terms are used in this report.

Infrastructure systems: include interconnected networks of physical infrastructure assets (both built infrastructure and nature-based infrastructure) and the enabling environment (also known as soft infrastructure) that enables them to function (i.e. provide services), across all infrastructure sectors. This report considers the following sectors as infrastructure: buildings, civic, culture and recreation, digital communications, education, energy, finance, health, manufacturing and production, retail, solid waste, transport, and water.

Built infrastructure: also known as hard or grey infrastructure, refers to built infrastructure assets, networks, and facilities that provide or enable the delivery of infrastructure services. This includes the built assets of all infrastructure sectors, such as hospitals in the healthcare sector, roads and railways in the transport sector, and power stations in the energy sector. For the purpose of this report, the term 'built infrastructure' is used.

Nature-based solutions (NbS): building on previous work by the International Union for Conservation of Nature (IUCN), the United Nations Environment Assembly (UNEA) (2022) defines NbS as "actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems that address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits." NbS are an umbrella term, bringing together different concepts, including ecosystem-based adaptation, ecosystem-based disaster reduction, green infrastructure, and natural climate solutions. They do not include nature inspired solutions (e.g. biomimicry) or nature-derived solutions (e.g. wind, wave, or solar energy or materials derived from timber). To be considered an NbS, a solution must provide both human benefits and biodiversity benefits.

Nature-based Infrastructure (NbI) solutions: sometimes known as green infrastructure, natural infrastructure, or ecological infrastructure, are a type of NbS that involve the protection, restoration, improved management or creation of natural and semi-natural ecosystems to provide services relevant to the functioning of infrastructure. NbI refers to all ecosystems, including those on land and in cities (terrestrial) or along the coast and in the sea (marine), such as forests, wetlands, urban parks, agricultural lands, beaches, seagrass, green roofs and walls. NbI can be strategically planned and managed to provide infrastructure services to different infrastructure sectors (Ozment et al. 2015). For example, wetlands can assimilate pollutants and reduce the need for built water treatment infrastructure, while mangroves, seagrass and reefs can protect coastal infrastructure from climate impacts such as coastal inundation and erosion. As with NbS, NbI solutions must provide both human benefits and biodiversity benefits. Benefits to biodiversity are a foundational property of NbI, and not simply an additional co-benefit – NbI must be implemented with this in mind, to ensure the health, resilience and long-term permanence of ecosystems that are used to provide infrastructure services.

Hybrid infrastructure: includes both built infrastructure and NbI and may also be known as green-grey infrastructure. For example, coastal ecosystems, such as mangroves, coral reefs and salt marshes can work together with built infrastructure such as seawalls to provide services that protect from coastal hazards (Green-Grey Community of Practice 2020). For the purpose of this report, the term 'hybrid infrastructure' is used.

Enabling environment: comprises the knowledge, institutions and policy frameworks associated with infrastructure, such as regulations, laws, human resources, financial resources, processes, tools, and information. It applies across the infrastructure lifecycle, from upstream strategic planning through to construction, operations, and decommissioning.

Sustainable infrastructure systems:
also sometimes known as green infrastructure systems, are systems that ensure sustainability across the whole infrastructure lifecycle, spanning planning, design, construction, operation, and decommissioning. Sustainable infrastructure ensures all aspects of sustainability, including economic, financial, social, environmental, and institutional, and embeds climate resilience. Such infrastructure can encompass built infrastructure, natural infrastructure, soft infrastructure, or hybrid infrastructure. For the purpose of this report, the term 'sustainable infrastructure' is adopted.

Climate-compatible development:
is "development that minimizes the harm caused by climate impacts, while maximizing the many human development opportunities presented by a low emission, more resilient future" (Mitchell & Maxwell 2010). It is central to the achievement of the Sustainable Development Goals (SDGs) and the Paris Agreement.

Climate resilient infrastructure: is defined by the Organisation for Economic Co-operation and Development (OECD) (2018) as infrastructure that has been planned, implemented, and managed in a way that anticipates, prepares for and adapts to changing climate conditions. It can withstand, respond to and recover rapidly from disruptions caused by these climate conditions. Such infrastructure can encompass built infrastructure, natural infrastructure, the enabling environment or hybrid infrastructure.

Key messages

The study identifies five functions through which NbI can provide benefits with respect to the provision of infrastructure services:

1. "Deliver" infrastructure services directly
2. "Enhance" the delivery of services by built infrastructure
3. "Protect" built infrastructure against the impacts of climate change and natural disasters
4. Provide benefits to "workforces" that contribute to infrastructure functioning
5. Provide "multiple additional benefits" beyond the delivery of infrastructure services.

For some types of NbI, such as those in the water sector, the primary function may be more obvious and well-reflected in cost-benefit analyses. However, the full range and combination of functions that NbI can provide across sectors are often overlooked. By undervaluing them, decision-makers risk missing targets under the SDGs, Paris Agreement and the Convention on Biological Diversity (CBD).

- **NbI can influence up to 79% of SDG targets across all 17 SDG Goals.** When NbI solutions are combined with built infrastructure assets, infrastructure systems can have greater cumulative impact on the SDG targets than either built infrastructure or NbI can alone, influencing up to 95% of SDG targets. This points to the importance of strategically planning integrated infrastructure systems for achieving the maximum possible progress on the SDGs.

- **NbI can provide critical benefits for addressing both the climate change adaptation and mitigation components of the Paris Agreement.** For adaptation, deployment of NbI can lead to: increased flexibility and adaptability of infrastructure systems, increased system-wide resilience across sectors, increased physical and mental resilience of workforces, as well as multiple additional benefits in terms of economic resilience, societal resilience, environmental resilience and the resilience of indigenous communities. For mitigation, deployment of NbI is central to carbon sequestration and avoiding land use change, but NbI can also play an important role in reducing greenhouse gas (GHG) emissions by substituting, complementing or protecting built infrastructure assets.

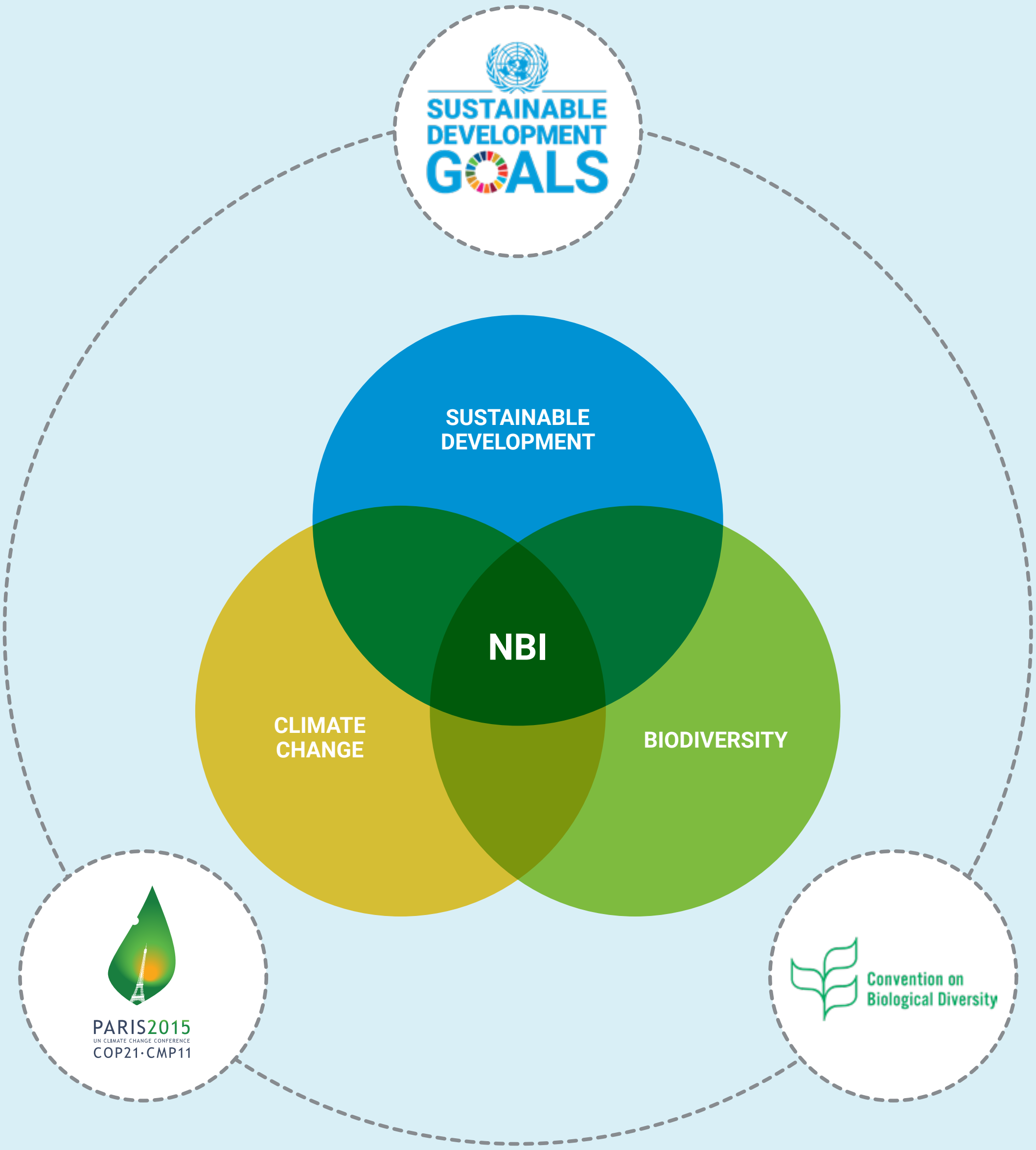
- **NbI can contribute to meeting three of the four long-term goals and 70% (16) of the targets of the Kunming-Montreal Global Biodiversity Framework (GBF) under the CBD.** Specifically, deployment of NbI can contribute to achieving the GBF through: ensuring biodiversity values are embedded in spatial infrastructure planning; reversed loss of nature; reduced pollution of nature from infrastructure; promoting increased biodiversity health and resilience; supporting increased awareness and education on the value of nature; providing benefits to indigenous people, women and children, and facilitating increased financial flows to nature.

- **NbI is the only way through which countries can achieve mutual, synergistic progress on the SDGs, GBF, and the Paris Agreement at the same time.** With its ability to deliver infrastructure services while also providing multiple additional benefits, NbI can provide opportunities to make progress on sustainable development, climate change and biodiversity simultaneously.

- **Deployment of NbI is complex, and there are barriers to mainstreaming NbI in the realm of sustainable infrastructure.** Key barriers to address include: limits to performance; variations in functional performance; time delays to benefit provision; the resilience of NbI (to persist, function and provide services); data and information availability; management and maintenance challenges in certain contexts; availability of human, technical and institutional capacity; inevitable trade-offs within the decision-making process; alignment and collaboration of multiple different stakeholders; costs and concerns around who pays, and the need for transboundary decision-making in certain contexts.

- **Maximizing the potential of NbI to address global sustainable development challenges requires harmonized actions by a broad range of stakeholders across the infrastructure lifecycle.** This ranges from visioning and strategic planning among policymakers, through to project prioritization and preparation, financing, design, construction, operations, and decommissioning.

Figure 1: NbI is the only type of infrastructure that can contribute to mutual, synergistic progress on sustainable development, climate change, and biodiversity



Introduction

Global challenges

Countries are facing the unprecedented challenges of meeting development needs and adapting to the impacts of climate change, while at the same time addressing global temperature increase and biodiversity loss. As of 2020, 2 billion people did not have access to safe drinking water, 733 million people lacked access to electricity, and 25% of primary schools did not have access to the basic services of electricity, drinking water and sanitation (United Nations [UN] 2022). In 2021, global mean temperatures reached 1.1°C above pre-industrial levels for the first time (World Meteorological Organization [WMO] 2022), closing in on the 1.5°C limit necessary to avoid the worst impacts of climate change on societies and biodiversity. Many climate impacts are already apparent – global economic losses from natural disasters were estimated at US $93 billion during the first half of 2021 alone, including US $42 billion of insured losses (Aon 2021). At the same time, the world is facing a global biodiversity crisis – only 3% of ecosystems globally remain intact (Plumptre et al. 2021), as much as 66% of the marine environment and 75% of the terrestrial environment has been significantly altered by human activities (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES] 2019), and 1 million species are considered at risk of extinction over future decades (IPBES 2019).

The role of infrastructure in global challenges

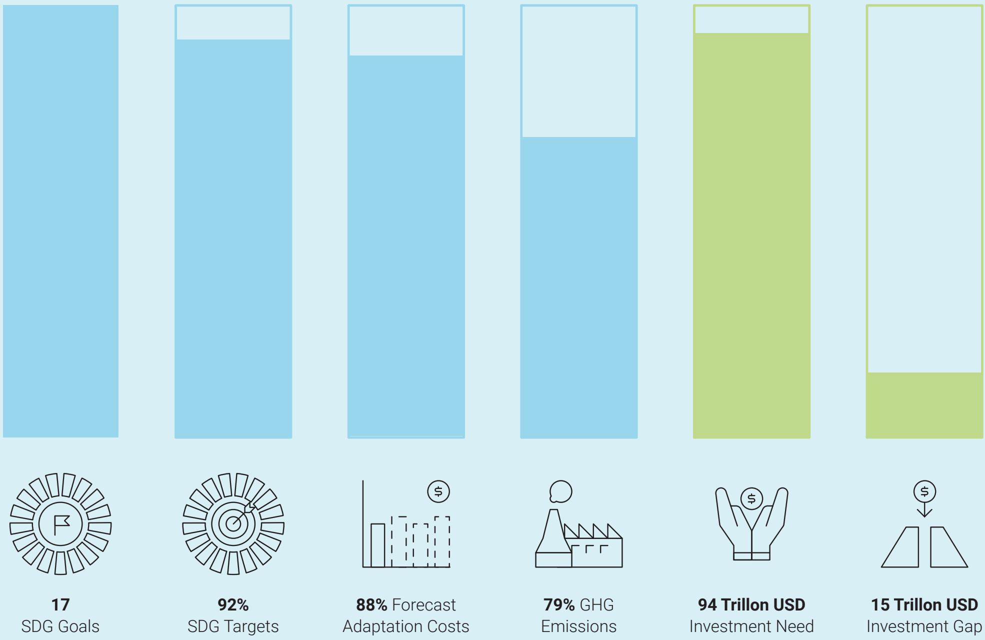
Decisions on infrastructure investment will have significant implications for whether or not these challenges can be overcome. Infrastructure systems are critical to development, underpinning the functioning of societies and economies through the provision of essential services including electricity, water, sanitation, healthcare, transportation, and communications. If the right infrastructure is designed and operated in the right way, infrastructure systems have the potential to contribute to all 17 SDGs, including 92% of the 169 SDG targets (Thacker et al. 2019), and to support both adaptation and mitigation efforts under the Paris Agreement (Thacker et al. 2021) *(see Box 1).*

Infrastructure systems consist of built infrastructure, natural infrastructure, and the enabling environment (Thacker et al. 2021). To date, infrastructure investments have focused predominantly on built infrastructure systems, at the expense of the natural environment. The development of built infrastructure impacts the natural environment in multiple ways, including through habitat fragmentation, biodiversity loss, pollution, exacerbation of soil erosion and nutrient leaching, and the use of natural resources as construction materials (Seiler 2003; Ibisch et al. 2016). A disproportionate emphasis on built infrastructure is driving climate change through embedded carbon and GHG emissions across the lifecycle, an issue that is compounded by the loss and degradation of natural carbon sinks. Many built infrastructure systems and their services are increasingly vulnerable to climate impacts, such as flooding, drought, and hurricanes, which threatens progress made to-date on the SDGs and risks stalling further progress through the need to divert funds away from the development of new infrastructure and to the repair and replacement of damaged systems (Fuldauer et al. 2022). There is a risk that continued overemphasis on built infrastructure systems may undermine progress on addressing these challenges, and lead to wider negative outcomes for human health, livelihoods, and biodiversity.

Nature-based infrastructure solutions

NbI offers decision-makers opportunities to address these challenges simultaneously and make progress on multiple development agendas including the SDGs, Paris Agreement and Convention on Biological Diversity *(see Figure 1)*, through strategic integration of NbI with built infrastructure systems. Studies have highlighted the potential for NbI to provide services relevant to infrastructure and sustainable development outcomes including freshwater provision, pollution

Box 1: Infrastructure systems are related to:



filtration, wave dissipation, flood regulation, urban cooling, and soil erosion regulation (e.g., Kapos et al. 2019; Vogl et al. 2016; Guannel et al. 2016; Faivre et al. 2017). NbI also provides multiple additional benefits, often referred to as 'co-benefits', such as carbon sequestration, air quality, empowered communities, and improved livelihoods, which are fundamental to meeting global challenges. By definition, in addition to infrastructure services, NbI must also provide benefits for biodiversity (International Union for Conservation of Nature [IUCN] 2020; Seddon et al. 2021), and these should be considered a foundational property of NbI, and not just an additional benefit. This is because the ability of ecosystems to provide services and their functional resilience to stressors such as climate change is strongly determined by ecosystem health, including ecosystem connectivity and diversity (Seddon et al. 2021; Key et al. 2022). The science-based idea of ecosystem health needs to be mainstreamed in infrastructure planning in order to safeguard ecosystem services, increase benefits to biodiversity, and maximize the potential for NbI projects to function long-term; not doing so increases the risk that an NbI project will fail.

The need to get infrastructure decisions right

There are huge global investment needs for infrastructure. It is estimated that almost US $100 trillion of investment in infrastructure is required globally between 2016 and 2040, across energy, transport, water, and telecommunications infrastructure (Global Infrastructure Hub 2017) - almost twice the value of existing infrastructure systems. The long lifespans of built infrastructure assets - spanning multiple decades or longer - high costs, and difficulty of reversal means that infrastructure investments lock in development outcomes, whether they be positive or negative, for decades to come (Thacker et al. 2019).
There is a risk that, if the right decisions are not made, infrastructure investment could lock in unsustainable, high carbon development, leave countries vulnerable to climate impacts, and cause the further fragmentation, degradation, and loss of natural ecosystems and their services (Hall et al. 2016). Furthermore,

Box 2: Biodiversity as a foundational property of NbI

By definition, NbI must provide both human benefits and biodiversity benefits (IUCN, 2020; Seddon et al, 2021). The benefits for biodiversity should be considered a foundational property of NbI, and not just an additional benefit. Infrastructure practitioners should implement NbI with this in mind to ensure the long-term health and functioning of ecosystems that are used to provide infrastructure services, and their persistence long-term. This is particularly important to maximize the resilience of natural ecosystems and the long-term success of NbI in the face of temperature increase and climate change impacts.

The ability of ecosystems to provide services and their functional resilience to stressors such as climate change is strongly determined by ecosystem health, including ecosystem connectivity and diversity (Seddon et al, 2021). The science-based idea of ecosystem health needs to be mainstreamed in infrastructure planning in order to safeguard ecosystem services, increase benefits to biodiversity, and maximize the potential for NbI projects to function long-term. Key pillars of ecosystem health include (Key et al, 2022):

- Diversity: including species diversity and genetic diversity, such as by restoring a mix of native species
- Biomass: including habitat extent, density, and stem density
- Ecosystem functioning and population dynamics: including age structure, recovery rate, resistance, and survival rate
- Ecosystem composition: including species abundance, community composition
- Habitat quality: including the presence of particular landscape features and soil quality
- Landscape structure: increased ecological connectivity and reduced landscape fragmentation
- Conservation status: change in conservation status or likelihood of extinction
- Unspecified: perceived overall change in ecosystem health

These pillars of ecosystem health are essential for the long-term sustainability of NbI, their ability to function and provide ecosystem services. If thinking in terms of benefits to biodiversity and ecosystem health is not embedded across the lifecycle of NbI projects, there is a large risk that funding will be channelled into projects that will ultimately fail.

if infrastructure systems are not designed to meet the service needs of different stakeholder groups - particularly women and girls - they risk exacerbating gender gaps and other inequalities (Morgan et al. 2020).

At the same time, large scale investment in nature is required to reverse the global loss of biodiversity. It is estimated that US $484 billion is required in NbS annually by 2030 (United Nations Environment Programme [UNEP] 2022) to meet global targets on climate change, biodiversity, and land degradation. With finite resources available to meet these challenges, funds need to be invested intentionally and wisely. There is a need to refocus infrastructure investments away from traditional 'business-as-usual' approaches, which default to built infrastructure solutions and typically work towards one policy agenda at a time (International Institute for Sustainable Development [IISD] 2021), towards solutions that serve to maximize benefits for development, climate change and biodiversity, and which minimize negative trade-offs that can undermine progress on global policy agendas. NbI offers potential as a synergistic approach to meeting these challenges and maximizing the use of financial resources. It is critical that NbI are factored into infrastructure and investment decisions from the beginning of infrastructure planning to ensure that new infrastructure development does not continue to cause the loss and degradation of ecosystems and their services, and to ensure that the potential of NbI to provide services for sustainable, climate-compatible development is maximized.

The following sections of this report provide a framework for thinking about NbS in the context of infrastructure and outline key benefits, challenges, and recommendations to support their scale-up in infrastructure planning, design, and implementation.

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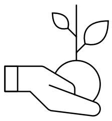
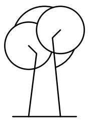
A framework for thinking about NbI

Following Haggis et al. (forthcoming), and building on the work of Ozment et al. (2015) and Browder et al. (2019), this report defines five functions through which NbI can provide benefits to infrastructure and beyond, with respect to the provision of services:



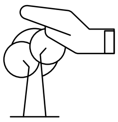
Deliver Function

Function 1: 'Deliver' the service directly, and as such either entirely or partially substitute for the built infrastructure asset. NbI can deliver infrastructure services that can reduce or avoid the need for built infrastructure assets.



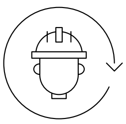
Enhance Function

Function 2: 'Enhance' the service delivered by an infrastructure asset, and as such complement that asset. NbI can enhance the functioning of infrastructure assets and systems, which can increase the quality and efficiency of service provision and reduce the need for maintenance and inputs.



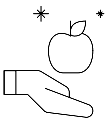
Protect Function

Function 3: 'Protect' the service delivered by an infrastructure asset and as such protect that asset or the key resources that the sector relies upon from climate change and natural disasters.



Workforce Function

Function 4: 'Benefit workforces' and as such benefit the human capital that underpins the provision of infrastructure services. Infrastructure service provision depends upon the people who work there - implementation of NbI in and around infrastructure assets can boost the functioning and health of infrastructure sector workers, which can lead to economic benefits for the sector in which the NbI is deployed.



Multiple Additional Benefits Function

Function 5: 'Multiple additional benefits', often termed 'co-benefits', beyond the primary intended infrastructure service for which the NbI is deployed. NbI can deliver a range of social, environmental, and economic benefits that can help to advance progress on the SDGs, the Paris Agreement, and the CBD.

NbI can perform multiple functions at the same time through the provision of many ecosystem services simultaneously. For example, street trees can 'enhance' the quality and reliability of mobility via roads by increasing driver attention span and reducing traffic accidents (Davies et al. 2014), while helping to 'protect' paved roads from heat via shading (McPherson and Muchnick 2005), and at the same time provide multiple additional benefits, such as carbon sequestration and air quality (Greater Manchester Combined Authority [GMCA], 2019).

By using this framework, practitioners are able think more systematically about the ways in which NbI can provide benefits to different sectors, and to communities more widely. This can provide a foundation for understanding the potential for nature to be integrated into infrastructure systems, and for embedding systematic consideration of NbI into the planning and design of sustainable infrastructure systems.

Potential Benefits of NbI

This study assessed the applicability of NbI in 13 sectors, which are shown in *Table 1* along with examples of built infrastructure assets in those sectors. The sectors were selected following previous work undertaken by UNEP, United Nations Office for Project Services (UNOPS) and the University of Oxford under the Sustainable Infrastructure Partnership (SIP). 'Buildings' has been included as a separate sector to reflect the fact that NbI can be applied similarly to the buildings of all infrastructure sectors.

Table 1. The 13 infrastructure sectors considered in this study, along with examples of built assets (UN, 2008)

Sector	Example built assets
Buildings	• Buildings across all infrastructure sectors, including airport terminals, offices, and residential buildings etc.
Civic	• Rule of law: offices of legal institutions, local authorities, and other public sector institutions. • Emergency response: police stations, fire stations, ambulance dispatch terminals.
Culture & Recreation	• Libraries, museums, archives, sports facilities.
Digital Communications	• Submarine cables, landing stations for submarine cables, terrestrial cables - underground and overland. • Internet exchange points and other data centres, wireless transmission infrastructure - towers and antennas.
Education	• Universities, schools, colleges, sports grounds (in the case of sport and recreation education).
Energy	• Hydropower: power plants, dams, reservoirs. • Non-renewable: oil refineries, oil fields, gas-fired power stations, nuclear power plants, thermal power plants. • Solar: ground mounted solar panels, roof mounted solar panels. • Transmission: pipelines, overhead power lines, pylons, underground power lines. • Wind: wind turbines.
Finance	• Credit agencies, banks, insurance and reinsurance companies.

Sector	Example built assets
Health	• Hospitals and other medical facilities, dentists, nursing care facilities, residential care centres.
Manufacturing & Production	• Processing plants, manufacturing warehouses, factories, distilleries.
Retail	• Retail stores, outlets, markets, stalls.
Solid Waste	• Solid waste treatment plants, recycling plants, disposal areas, e.g., landfill, incinerators, composts, fermenters.
Transport	• Air: airport terminals, runways and landing strips, grounds. • Rail: railway tracks, railway stations, signal boxes. • Road: paved and unpaved roads, service stations. • Water: shipping ports, harbours, shipping channels, inland navigation ways including rivers and canals, container terminals.
Water	• Potable water: reservoirs, boreholes, water treatment plants, pipelines, building rainwater harvesting. • Wastewater: wastewater treatment plants, pipelines. • Surface water management: levees, flood walls, dams.

Assessment of the scale of benefit that NbI can provide to infrastructure

Through a systematic assessment, this report finds that all infrastructure sectors can integrate NbI through one or more of the five functions defined in the previous section. *Table 2* indicates which of the five functions apply to each infrastructure sector. Illustrative examples of the applicability of NbI to each sector are outlined below.

Table 2. The applicability of different NbI functions to infrastructure

Sector	Deliver	Enhance	Protect	Workforce	MAB
Buildings		●	●	●	●
Civic			●	●	●
Culture & Recreation	●	●	●	●	●
Digital Communications			●	●	●
Education		●	●	●	●
Energy		●	●	●	●
Finance		●	●	●	●

Sector	Deliver	Enhance	Protect	Workforce	MAB
Health	●	●	●	●	●
Manufacturing & Production		●	●	●	●
Retail		●	●	●	●
Solid Waste		●	●	●	●
Transport		●	●	●	●
Water	●	●	●	●	●

● A circle indicates that the function applies to that sector.

* MAB: Multiple Additional Benefits

Deliver function

There is opportunity for NbI to substitute for built assets, either entirely or partially, to directly deliver services in the culture and recreation, health, and water sectors.

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Culture & Recreation

Beyond built infrastructure assets, such as museums and art galleries, the culture and recreation sector includes nature reserves, urban parks, botanical gardens, heritage sites (including natural heritage) and bathing beaches (UN 2008). Consequently, the deployment of NbI can deliver the services of the sector directly. United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Convention has formally recognized the heritage value of natural ecosystems including the Serengeti National Park, the Great Barrier Reef, and the Sundarbans mangrove forest.

Health

NbI can be an important asset for the delivery of improved mental and physical health outcomes. The European Centre for Environment and Human Health has created a 'Nature on Prescription Handbook' to highlight the benefits that nature can provide for mental health, including through horticulture and gardening, walking groups, nature appreciation, and conservation (Fullam et al. 2021). Nature therapy is considered to provide preventitative medical benefits, via physiological relaxation and stress recovery, and potential solutions for elderly patients undergoing rehabilitation and those who experience high mental stress and physical pain (Jo et al. 2019). The benefits of nature for preventing physical health issues are also evidenced, including for heart rates and blood pressure, stress levels, obesity, type 2 diabetes, post-operative recovery, birth weight, cardiovascular disease, and improved immune responses (World Bank 2021).

Water

NbI is highly intertwined with water and can potentially substitute for built infrastructure to deliver all services of the sector, including the provision and storage of freshwater, the maintenance of water quality, treatment of wastewater supplies, and the regulation of flooding. It is reported that as much as 90% of New York City's water is provided by three protected watersheds, which are 75% forested, and improved agricultural management programmes, which together reduce the need for built water treatment infrastructure (Browder et al. 2019). Infrastructure planners and investors have a huge opportunity to meet water-related needs whilst scaling the protection and restoration of natural ecosystems through investments in NbI and should look to prioritize NbI over or alongside built infrastructure options in the sector where possible.

The substitutability of NbI with built water infrastructure is well recognized (e.g. United Nations World Water Assessment Programme [WWAP] 2018). However, the ability of NbI to deliver the services of the culture and recreation sector and the health sector is relatively less well-known, and therefore at risk of being omitted in infrastructure decisions. The systematic consideration of NbI across these sectors can help to ensure that these benefits are recognized and incorporated into national development strategies where possible.

Enhance function

There are several opportunities to integrate NbI in order to complement built infrastructure assets and positively contribute to the provision of infrastructure services across different sectors.

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Buildings

There is scope to integrate NbI into buildings to support their functioning. This includes the creation of gardens, green walls and roofs, which can provide thermal regulation and reduce the need for heating and cooling (Ezri et al. 2017), and constructed wetlands, which can support sanitation (UNEP 2014). For example, Incheon airport in South Korea has planted native foliage – this helps to cool airport buildings and reduce the need for air conditioning, leading to energy savings for the airport (Peters 2016).

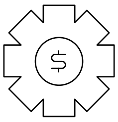
Education

NbI can provide various services that underpin positive educational outcomes, such as the development of creativity, increased attention span, increased cognitive functioning and cognitive development (Stenfors 2019; Bratman 2015). Studies report that NbI can lead to improved progress in working memory and reduced inattentiveness (Dadvand et al. 2015). For example, in the Netherlands, children in classrooms with green walls scored better on a test for selective attention than those in classrooms without green walls (van de Berg et al. 2016). Engagement with green space is linked to improved behavioural development, reduced emotional symptoms and peer relationship problems, and reduced rate of Attention Deficit Hyperactivity Disorder (ADHD) in children (Amoly et al. 2014). Educational gardens can provide opportunities for disabled and special need students to connect with nature through sensory stimulation and undertake interactive learning (Hussein 2010; Hussein 2012). NbI can also facilitate student learning about nature and the environment, increase connections to nature, and boost pro-environmental behaviours, which is of high importance given the current climate and biodiversity crisis (Kuo et al. 2019).

Energy

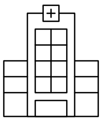
NbI can provide many benefits to the energy sector. For example, in the solar sub-sector, green roofs can act as a ballast to keep solar panels anchored on the roof, while the evapotranspiration of plants helps to keep solar panels cool, and can increase their productivity rate by as much as 20%[1] (Enzi 2017; Semeraro 2020; Kaewpraek et al. 2021). Within the energy transmission subsector, the EU Elia project has demonstrated that protection and restoration of low-lying NbI, including orchards, ponds and wetlands, around overhead transmission infrastructure can prevent the growth of vegetation that can interfere with transmission lines and decrease the reliability of energy transmission (Life Elia 2021). Within the hydropower subsector, NbI such as the protection of forests and improved agricultural management practices, can provide services that reduce flows of sediment into water channels supplying hydropower reservoirs. This can result in benefits including (a) reduced turbidity, which reduces wear and tear on hydropower dams and turbines; (b) reduced requirements for dredging to preserve storage capacity from sedimentation; (c) increased built infrastructure lifespans and reduced requirements for repair of components; and (d) increased productivity and efficiency of energy generation (Browder et al. 2021; Ozment et al. 2015; Stickler et al. 2013; Waves 2015).

1. The productivity of solar panels is reduced when air temperatures exceed 25°C (Enzi et al. 2017).



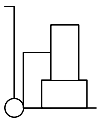
Finance

The majority of insurance and re-insurance stakeholders do not regularly assess nature-related risks but have an opportunity to benefit from integration of NbI within the sector (Cambridge Institute for Sustainability Leadership [CISL] 2022). Benefits that NbI can provide include lower frequency and severity of insurance claims, increased resilience of clients, and lower insurance premiums (CISL 2022; Golnaraghi and Mellot 2022; Kousky 2022). There is scope for NbI to be used more systematically amongst companies within the insurance and reinsurance industries to simultaneously enhance the provision of the service whilst protecting and restoring natural ecosystems.



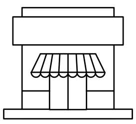
Health

The deployment of NbI can provide various health benefits that can complement built infrastructure service provision within the health sector. For example, therapeutic gardens can speed up recovery time and reduce the length of stays in hospital (Viray 2018; Newman 2018; Raanaas et al. 2011; Ulrich et al. 1984), lead to reduced stress in hospital waiting rooms (Beukeboom et al. 2012) and provide restorative qualities in hospital break areas (Nejati et al. 2016).



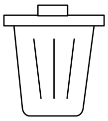
Manufacturing & Production

The use of constructed treatment wetlands, reed, and pond systems can treat wastewater streams arising from various industrial processes (Vymazal 2022), including manufacturing and production. For example, they have been demonstrated for the treatment of effluents including dairy, abbatoir, meat processing, pulp and paper, as well as for wineries, breweries, vegetable processing, soft drink processing, wood and leather processing, tanneries and olive mills, and within the textile industry (Stefanakis 2018; WWAP 2018). Wastewater treated using constructed wetlands can be reused for non-drinking purposes (Kesari et al. 2021), which offers potential for NbI to contribute to the reuse of water within the processes of the manufacturing and production sector. Constructed wetlands also offer the added benefit of being able to provide wastewater treatment at the location in which it is produced. The opportunities for using constructed treatment wetlands for industrial wastewater treatment depend upon the pollutant type and its loading (WWAP 2018). Built infrastructure may still be required for more toxic substances associated with industrial discharge and to avoid contamination to wetlands and damage to their functioning and health (ibid.). Some NbI species may also require longer retention times to filter pollutants, but should still be considered alongside conventional water treatment infrastructure within the manufacturing and production sector (ibid.).



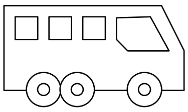
Retail

Deployment of NbI around retail outlets has been shown to enhance customer footfall and increase sales. For example, Wolf (2003) found that urban forests increase willingness to pay by 10% in inner-city business district in US cities. Wolf (2005) reported that trees help to form more positive consumer experiences in central business districts, and visitors are willing to spend 9-12% more on goods and services, with larger increases in spending arising from higher quality tree canopy cover. Han and Hyun (2018) found that NbI can influence customers, including their approach or avoidance behaviour, and their loyalty. In a time when many high street shops are closing, decision-makers have an opportunity to integrate NbI into retail areas as part of strategies to support local economic growth and development.



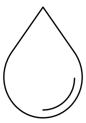
Solid Waste

The closure of modern landfills typically involves the capping of waste with clay to prevent the percolation of water into waste, control the movement of leachates, reduce the emission of gases and their odours, and prevent environmental contamination from water overflow and runoff (Lamb et al. 2019; Khapre et al. 2019). Clay capping solutions are considered increasingly ineffective in reducing percolation of water into waste, owing to the possible cracking of the clay material, which can provide space for water to infiltrate. Phytocapping is an alternative solution, which uses plants to prevent water entry into landfill via three mechanisms: 1) the interception of rainfall by plant canopies; 2) the storage of water in the soil; and 3) evapotranspiration of water (Lamb et al. 2019). Phytocapping is considered at least as effective as clay capping in reducing percolation into landfill, and can increase cap stability, reduce erosion of capping materials, and reduce wind-blown dust (ibid). Equally, while clay covers can deteriorate over time, phytocaps have a longer lifespan. Constructed wetlands can also be deployed to treat leachate streams arising from landfill, reducing requirements for built infrastructure (Kumar and Choudhary 2018).



Transport

There are various opportunities to increase the integration of NbI into transport infrastructure in order to benefit service provision. For example, tree lined roads make it feel like the road is narrower and encourage slower driving, can increase driver attention span, and can also act as a buffer between pedestrians and road vehicles (Davies et al. 2014). This can lead to increased road safety through reduced road traffic accidents (GMCA 2019). NbI along navigation[2] channels in the water transport sector can maintain tranquil waters and prevent sedimentation of shipping lanes (Hijdra et al. 2021; Almstrom et al. 2022). NbI can equally be deployed within airports. For example, the UK's London Heathrow Airport uses reeds and ponds to treat wastewater streams including anti-icing fluids (Airport Technology [AT] 2016). NbI can also be deployed along railway networks to increase the reliability of rail transport and reduce maintenance requirements (Varley 2018).



Water

Integration of NbI within the water sector can enhance service provision by reducing sedimentation of water supplies and the associated need for maintenance such as dredging. The protection of forests and wetlands within water catchments, improved agricultural management practices, such as reduced grazing density, and the restoration of riparian vegetation can help to stabilize soils, reduce soil erosion, and prevent sediments from entering water courses, reducing requirements for dredging. Correspondingly, the loss and degradation of natural ecosystems can lead to reduced functioning of the water sector. For example, the conversion of natural landscapes to agriculture within the catchment supplying the Tana River in Kenya, which provides 80% of Nairobi's drinking water, has reduced the storage capacity of water reservoirs and increased requirements for water treatment (WWAP 2018).

Given that built infrastructure assets provide the primary infrastructure service of the majority of these sectors, many of the complementary services of NbI may be less apparent to infrastructure decision-makers, and therefore at risk of being overlooked. However, through integration with built infrastructure systems, practitioners have an opportunity to increase the quality and reliability of the infrastructure service and at the same time help to make space for nature.

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2. NbI are not considered to deliver the service of water navigation directly. This is owing to the need for NbI to provide simultaneous benefits to humans and biodiversity – the use of navigation channels by ships, boats and other vessels is likely to result in ecosystem degradation rather than biodiversity benefits.

Case study:

Life-Elia-RTE, Belguim

Location:
Belgium

Source:
Life-Elia-RTE (2018)

The LIFE Elia-RTE project was a six-year project started in 2011 by the European Union (LIFE programme), Elia (Belgian Transmission System Operator), and RTE (French Transmission System Operator), that implemented alternative vegetation management practices under high-voltage overhead transmission lines in the Walloon region of Belgium.

Vegetation under overhead powerlines is typically managed with heavy machinery and aggressive clearing practices that have a negative impact on biodiversity and ecosystem functioning. Under the project, innovative measures were applied that allowed operators to enhance the safety of the transmission corridors while reducing the area that needed clearing and mowing, increasing biodiversity and ecosystem health, and improving the aesthetic and recreational values of the surrounding forests. Specific measures included:

- Planting and restoration of forest edges
- Planting fruit trees of wild and local species
- Restoration of natural habitats protected by the European Union's Habitats Directive (bogs, moors, chalky grasslands and lean meadows)
- Digging of ponds
- Establishment of a pasture or mowing
- Combating invasive plant species
- Harvesting seeds, sowing and mowing of flower meadows

Long-term monitoring shows that these measures achieved their biodiversity objectives in 79% of the sites where measures were implemented, with the pre-intervention status quo maintained in another 19% of sites (Godeau et al. 2020). Cost-benefits analysis showed that while these alternative methods had a higher up-front cost, they are 1.4 to 3.9 times less costly over a 30 year timespan.

Protect function

This report finds that deployment of NbI could help to protect infrastructure in all sectors from the impacts of climate change and natural disasters. Climate impacts, such as floods, droughts, and landslides, pose risks to infrastructure and societies across the world. Evidence is growing that natural ecosystems can reduce these risks and support adaptation to a broad range of climate hazards (e.g., Chausson et al. 2020). Since the protect function applies to all sectors, the discussion below is organized around the types of risks that NbI can protect against, rather than by sector.

Surface floods

Different NbI options can be effective for supporting the mitigation of surface flooding (Intergovernmental Panel on Climate Change [IPCC] 2019) and the impact of floods on built infrastructure systems. This includes the protection and restoration of natural wetlands, peatlands, forests, ponds and lakes, improved agricultural management, and the creation of constructed wetlands (Chausson et al. 2020; Dadson et al. 2017). The mechanisms through which NbI can contribute to flood mitigation include through evapotranspiration, increased water infiltration into the soil, increased water storage capacity, and alterations to the timings of water flows through a reduction of water flow velocity (Moos et al. 2018; Broadmeadow et al. 2018). Evidence suggests that NbI solutions are less impactful for mitigating large floods, or floods at the scale of big watersheds, but can be effective in contributing to flood reduction in minor to moderate floods that occur at frequencies of up to one-in-100 years, in small and medium sized watersheds, and in catchments with low rainfall and deep soils (UNEP 2014; Dadson et al. 2017). The use of NbI for protecting infrastructure from flooding has been documented in the case of railway networks, where the protection of forests can help to reduce the impact of high precipitation onto railways and the risk of earthwork failure (Blackwood et al. 2022).

River floods

In many cases, decision-makers invest in built infrastructure options, such as dams, levees, channel modifications and flood walls, for the management of river floods (UNEP 2014; Dadson et al. 2017). However, NbI can provide alternative or additional options to built infrastructure solutions. They can store water, manage hydrological connectivity and conveyance of water, and preserve the water storage capacity of rivers through reducing sedimentation (Dadson et al. 2017; Browder et al. 2021). As with surface floods, NbI can store water and release it over time (Dadson et al. 2017). Tree shelterbelts at the bottom of grassland slopes can intercept water and reduce peak flows (Chausson et al. 2020). Improved grazing management can reduce soil compaction, leading to increased infiltration and reduced water runoff to rivers. Riparian and floodplain forests increase surface roughness, which can slow water runoff, and reduce peak river flows. NbI can also preserve the capacity of rivers to store and convey water by preventing sedimentation of river channels (Broadmeadow et al. 2018; Dadson et al. 2017). For example, riparian buffer strips of 10-30m around river channels can prevent sediments entering river channels, and wetlands can trap up to 80-90% of sediment from runoff (WWAP 2018). In some cases, such as slope revegetation and wetland protection, NbI can be more effective at flood mitigation than built infrastructure options such as check dams, artificial water storage and buffer tanks (Chausson et al. 2020). As with surface floods, the role of NbI in river flood mitigation is considered most effective at small spatial scales (less than 20km^2)[3] and for small floods, and less so for the most extreme floods (Dadson et al. 2017). The impact of NbI on sediment reduction and river channel storage capacity is often overlooked in flood risk assessments, but likely to be important in rivers that receive high rates of sediment delivery (ibid.).

Urban floods

There is potential to integrate NbI into urban areas to support the mitigation of urban flooding, avoid flood damages to infrastructure in urban areas, and relieve pressure on built flood management infrastructure. Green roofs, green walls, and green spaces, such as bioswales, wetlands, and urban parks, can help to absorb water, increase infiltration of water into the ground, and minimize the amount that remains as surface water (UNEP 2014; Chausson et al. 2020). Equally, restoration of urban water courses, riparian vegetation along riverbanks, and the protection or reconnection of floodplains can help to store urban water runoff (Dadson et al. 2021).

Drought

Multiple infrastructure sectors are dependent upon a supply of water to operate, and are therefore impacted by drought. This includes sectors such as water, energy (hydropower) and transport (water transport), which rely upon water for the provision of their service. It also includes sectors such as manufacturing and production, which use water in production processes; energy (non-renewable), such as through the use of water for cooling within thermal power plants; and by the fire service within the civic sector. NbI can support the mitigation of drought through processes including the storage of water, infiltration of water and recharge

of groundwater supplies, and by supporting water reuse (UNEP 2014). Both natural and constructed wetlands can store water during wet periods that can be used during subsequent dry periods. For example, in Zambia, one third of the Kafue river, which supplies two hydropower reservoirs and 40% of Zambia's electricity, flows through the Lukanga Swamp.
The swamp can store up to 10,000 million³ of water, which it releases during the dry season, safeguarding water flows and protecting hydropower-based energy generation within the country (Opperman et al. 2021). While many forests can reduce water availability, cloud forests can capture rainfall and support the supply of freshwater to rivers, helping to reduce water scarcity (Browder et al. 2019). Regional forests can increase water flows by impacting rainfall flows through evapotranspiration - Stickler et al. (2013) found that under business-as-usual projections of 40% forest loss by 2050, simulated hydropower generation declines to 25% of maximum energy output in the Amazon Basin. Improved agricultural practices can improve the water retention capacity of soils, such as through furrow diking, reducing tillage, maintaining mulch cover and improving soil organic content, which reduces pressure on water supplies for irrigation (Browder et al. 2019). Reduced grazing density can minimize the compaction of soils and enable the infiltration of water into soils and the recharge of groundwater supplies. Forest shelterbelts can reduce wind speed over fields, which can reduce water lost through evaporation (ibid.). Constructed treatment wetlands can treat wastewater streams, which can be subsequently reused, including in the provision of water supplies for the fire service, reducing pressure on supplies to water reliant sectors (Kesari et al. 2021).

Heat

Rising temperatures pose a risk to the functioning of infrastructure, such as roads and railways, which can suffer structural damage during periods of extreme heat. NbI can help to mitigate the impact of rising temperatures on infrastructure through processes including evapotranspiration and shade provision. Evapotranspiration can lead to cooling of local temperatures and reduced peak summer temperatures by 1-5°C (2-9°F) (World Bank 2021). Even small green spaces in cities can have a cooling effect – a green space in Lisbon, Portugal, which was 0.24 ha, had a cooling effect of 6.9°C compared to the surrounding area (Browder et al. 2019). It is reported that shaded surfaces can be as much as 11-25°C (20-45°F) cooler than the peak temperatures of unshaded materials (World Bank 2021). Studies have shown that the shading effect of street trees can protect asphalt concrete pavements from heat along road networks, leading to reduced fatigue cracking, increased durability and better pavement performance, less frequent requirements for repairs such as repaving, and associated cost savings (McPherson and Muchnick 2005). It is reported that repaving could be delayed by ten years in the case of a street that is well-shaded, and up to 25 years on streets that are heavily shaded, based on a Californian study (ibid). Similarly, development of green corridors along railway networks can increase shade provision from vegetation and protect railways from high temperatures, leading to reduced risk of the buckling and breakage of railway tracks (Blackwood et al. 2022).

Fire

Wildfire is intrinsic to the composition, structure and dynamics of many ecosystems (Chausson et al. 2020). However, studies have shown that NbI can be part of strategies to reduce the severity, incidence or spatial extent of wildfires (ibid.). For example, restoration of rangelands and savannas can improve ecological processes and fire resistance (Kapos et al. 2019). Management strategies that include the removal of invasive, fire-prone species, and the restoration of native, fire-resistant species can be part of fire adaptation strategies.

High wind

There is potential to deploy NbI as part of strategies to reduce the impact of wind on infrastructure systems. For example, shelterbelts along railway networks can protect railways from high winds and reduce wind loading onto structures such as railway masts (Blackwood et al. 2022). Mangroves can protect coastal infrastructure networks from the impact of wind - it is reported that mangroves can reduce mean wind speeds of up to 5 m/s by more than 85% and for winds greater than 15m/s by more than 50% (Browder 2019). The use of improved agricultural management practices, such as terraces or cover crops, can help

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3. Measured data on the impact of NbI on river flooding at large spatial scales (100 km²) is lacking (Dadson et al. 2017).

to reduce wind-induced soil erosion from croplands, helping to safeguard water supplies to water and hydropower networks.

Landslides

In sloped areas, landslides can pose a serious risk to infrastructure systems. Built infrastructure approaches to protect against landslides may be expensive to implement and maintain, but there are opportunities to use NbI as part of strategies to mitigate the likelihood of landslides, to reduce their runout distance, slow the movement of slipping soil masses and redirect their flow paths (Chausson et al. 2020; Moos et al. 2018). Vegetation cover has less effect on deep-seated landslides (depth of sliding surface >2m), as tree roots only penetrate the top layer of soil, and in cases where rainfall is heavy and continuous, but trees and shrubs can contribute to the mitigation of shallow landslides (depth of sliding surface <2m) through a number of mechanisms (IPCC 2019; Moos et al. 2018). They can enhance soil strength and reinforce soil layers, provide anchors into deeper and more stable substrates through dense lateral root systems, act as barriers against the movement of rock, debris and soil movement, limit landslide run-out distance, lower soil moisture levels through interception, evaporation and transpiration, and improve drainage (IPCC 2019; Moos et al. 2018). The hydrological effect of forests is considered relevant for hillslopes that drain large contributing areas, but less so for short hillslopes where landslides are triggered by short intense rainfall (Moos et al. 2018). Studies have shown that landslides become more frequent and extensive following deforestation of steep sloped areas, which is associated with the loss of tree roots that provide soil stability (Lehmann, von Ruette, and Or 2019; Shmaltz et al. 2017). Forest clear-cutting in regions with steep topography and high rainfall has reported to increase landslide events by two to ten fold relative to vegetated slopes (Lehmann et al. 2019). Where forests are removed, there is a higher frequency of shallow landslides one to five years after forest harvesting (Moos et al. 2018). The impact of NbI on landslides will depend on species, age, substrate and relief. The dimensions of forests and their structural characteristics, such as forest gaps, may limit their protective effect in some cases (ibid.).

Snowfall

Snow can accumulate on built infrastructure assets such as roads, railways, and airports, and disrupt their functioning and capacity to provide services. NbI, such as grasses, shrubs and trees, can form living snowfences, and provide alternative options to built fences. They can be designed specifically to divert snow so that it falls and accumulates in predictable locations (Kuhn, Hanley and Gehrlnger 2009; Daigneault and Betters 2000). Living snow fences are reported to have much longer lifespans than built infrastructure, of approximately 50-75 years compared to five to seven years for a typical slatted fence, and can trap blowing snow at an efficiency of 79% (Blanken 2018).

Avalanche

There is scope to use NbI to mitigate the risk of avalanches to infrastructure, particularly through the protection of forests on steep slopes. Moos et al. (2018) report several physical processes through which forests can help to reduce the risk of avalanches, mostly through the stabilization of snow cover: (1) the branches of trees can intercept 5-60% of falling snow, resulting in snow packs that are less thick and more variable in structure in forests compared to open surfaces; (2) forests reduce both incoming and outgoing radiation – this means that frost, which can lead to weak layers in the snow pack, forms less frequently in forested terrain than non-forested terrain; (3) forests reduce wind speed, leading to a more uniform distribution of snow and reduced formation of wind slabs; (4) tree stems, roots and woody debris can stabilize snowcover and increase the roughness of the land; (5) forests can influence the flow path of avalanches and their runout distance, predominantly in the case of small avalanches that occur within the forest or only short distances above the tree line. The extent to which NbI can contribute to avalanche mitigation depends on factors including tree density, tree height relative to maximum snow depth, gap size and species. NbI are likely to be less effective on larger avalanches that can reach high velocities of 80 m/s and knock down trees (ibid.).

Rockfall

In the area at which rock falls originate, the roots of vegetation can increase the risk of rockfall by growing into rock cracks and causing the displacement of rocks, particularly during strong wind. However, NbI can provide a protective effect against falling rocks in the flow pathway or deposition area, which can help to mitigate the impact of rockfalls onto downslope infrastructure. Trees can act as a barrier that can slow down, reorientate or stop falling rocks. Large rock falls can generally not be stopped by forests, however their spatial extent can still be reduced (Moos et al. 2018).

Debris flow

Debris flows transport a mixture of water and solid material, such as soil and fragmented rock, downslope in steep mountainous channels (Moos et al. 2018). NbI can contribute to the mitigation of debris flows and their impact on infrastructure systems through similar processes to those of avalanches and rockfalls, as outlined above. In addition, NbI, such as the protection or restoration of native vegetation, can also contribute to debris flow reduction through increasing the roughness of channels – this can lead to energy dissipation and reduced debris flow intensity. The presence of trees may also lead to changes in flow direction angle. It is reported that there is an increased likelihood of debris flows in the absence of vegetation, generally within one to five years after harvesting (ibid.).

Coastal flooding

Adaptation options to protect infrastructure systems from coastal flooding often rely upon built infrastructure solutions, such as sea walls, dykes, levees and breakwaters. However, NbI can provide alternatives or additional approaches to coastal flood mitigation, and can minimize flood damage to infrastructure and the intrusion of salt water into the water supplies of water-reliant sectors (Chausson et al. 2020; UNEP 2014). For example, coastal NbI, such as the protection, restoration and management of coral reefs, beaches and dunes, seagrass and mangroves, can be effective at reducing wave heights and energy, and minimizing the impact of coastal hazards (Ferrario et al. 2014; Narayan et al. 2016; Tiggeloven et al. 2022). Coral reefs can act as natural breakwaters and contribute to flood reduction through wave breaking and the attenuation of wave energy (Beck et al. 2018). Mangroves can provide physical defences against flooding, and increase bottom friction (Menendez et al. 2020). The flood protection benefits of coastal ecosystems, such as coral reefs and mangroves, are considered particularly critical for small island and developing states, such as Madagascar, Belize, and Bangladesh, which have limited capacity relative to their GDP to respond to flooding (Beck et al. 2018). There is potential to overlook the protective services of submerged ecosystems, such as coral reefs and seagrass, which are less visible than ecosystems located above water (Beck et al. 2018). The systematic consideration of these ecosystems within the portfolio of coastal flood adaptation options will be important to ensure that the benefits that they can provide are recognized.

Coastal erosion

Coastal NbI can reduce coastal erosion that can pose a risk to infrastructure systems. For example, coral reefs form a natural barrier and act as the first line of defence from coastal erosion by

reducing wave velocity, and by reducing non-storm wave heights by 70% (Ferrario et al. 2014). Seagrass helps to stabilize sediment and regulates water currents that contribute to coastal erosion, and can reduce non-storm wave heights by 36%. Salt marshes can stabilize coastlines by trapping sediment and reducing velocity, and are reported to reduce non-storm wave heights by 72% (UNEP 2014; World Bank 2021). The aerial roots of mangroves can retain sediments, stabilize soils in intertidal areas, and reduce coastal erosion, while reducing wave heights by 31% (Menendez et al. 2020). Oyster reefs, similarly to coral reefs, can protect shorelines from coastal erosion by reducing water velocities and increasing sedimentation rates. Sandy beaches can prevent coastal erosion caused by strong winds, waves, and tides. Dune systems can buffer storm erosion and help coasts to recover by naturally nourishing the shoreline, serving as reserves of sand (World Bank 2021). Vegetation on dunes can trap and store sand, which allows them to grow and provides additional protection from erosion.

Storm surges

The roots, trunk and canopy of mangroves can help to dissipate storm surges, and their impact on infrastructure systems, including through reducing peak water levels and flood depths where they are present over large areas (Menendez et al. 2020). Every mile of continuous wetland is reported to reduce storm surges by 8-20cm by increasing energy dissipation in the intertidal zones and reducing incoming wave energy (UNEP 2014). Salt marshes of 6-10km wide can reduce storm surges by increasing flow resistance (World Bank 2021).

Tsunamis

Coastal NbI can contribute to the mitigation of tsunamis and their impact on coastal infrastructure systems. For example, while small areas of mangroves are reported to have limited impact on tsunamis, wider mangrove belts, of 100m width or more, can contribute to the reduction of tsunami waves (World Bank 2021). Mangroves of 200m width are reported to reduce inundation depth, area and run-up distance by 10%. Mangroves can reduce tsunami flood depth by 5-30% during tsunamis of three-meter inundation depth and 30-minute wave period when mangroves are several hundred meters wide (Browder et al. 2019).

The hazards outlined above pose risks to infrastructure systems around the world. Through consideration of NbI during the development of adaptation strategies, decision-makers of all sectors can play a key role in scaling the uptake of NbI, reducing risk to built infrastructure systems, and reversing the loss of nature.

Case study:

Natural ponds restoration as water reservoirs and sustainable drainage for flood protection in Mannar, Sri Lanka (UNOPS)

Location:
Sri, Lanka

Source:
UNOPS (2016)

The monsoon season brings torrential rainfall to Mannar Island, in Sri Lanka, home to over 30,000 people. Decades ago, more than 70 ponds provided natural drainage and flood protection to this area, but over time many of these were filled in to reclaim land for planned and unplanned settlement and construction of buildings. This resulted in heavy flooding forcing inhabitants to flee to higher grounds, making public spaces and services inaccessible for days, and led to food shortages and economic losses due to the damage.

With the funding of the European Union, UNOPS, the Mannar District Secretariat and Mannar Urban Council collaborated to restore the natural ponds to act as cost-free flooding and water storage solutions, and helped improve the drainage systems through the construction of drainage canal networks. The pond rehabilitation works required considerable preparatory work and effective coordination and cooperation with the local population.

The pond rehabilitation work has already shown positive signs of minimizing flood damage and has helped to increase the water retention capacity by 8,840 m³. This allows the ponds to capture more water runoff, which reduces flood risk, and helps increase water infiltration, which improves ground water quantity and quality, increasing local communities' access to clean water.

Case study:

Ecosystem-based adaptation to reduce vulnerability in the United Republic of Tanzania (UNEP)

Location:
Coast of Dar es Salaam, United Republic of Tanzania

Source:
UNEP (2019) and UNEP (n.d.)

The Indian Ocean coastline of the United Republic of Tanzania is vulnerable to increased tidal activity and storm surge rise from climate change. This causes coastal erosion and flooding, threatening the livelihoods and wider economy of coastal communities. In Dar es Salaam, US $5.3 billion in public and private assets are at risk from flooding.

In this context, the Vice President's Office partnered with UNEP and UNOPS to implement specific ecosystem-based adaptation measures and reduce vulnerability. Funded by the Adaptation Fund, the project focused on coastal rehabilitation and planting of vegetation as a means of protecting other key infrastructure assets along the coast, including roads, buildings, ports and markets.

NbS interventions included mangrove forest and coral reef restoration, and revegetation of slopes with deep-rooted flora. In all, 1,000 hectares of mangroves, 3,000 m^3 of coral reefs, and 30,000 m^2 of shoreline vegetation were rehabilitated. The coral reef at the Sinda and Mwakatunde island marine reserves off the Dar es Salaam coastline were rehabilitated by transplanting and grafting bleaching-resistant corals brought from other locations. Indigenous trees and grasses were planted along select locations, including seawalls, with the aim to stabilize soils against encroaching erosion. Mangrove forests were rehabilitated through the planting of resilient seedlings, dredging and the creation of no-take buffer zones.

The restoration was carried out using locally available, climate-resilient species, and is estimated to have benefitted some 8,600 people via flood protection and livelihood opportunities, whilst also providing habitats for wildlife. To address unsustainable harvesting practices, no-take zones were established with a goal to reduce deforestation by 40% in the restored sites, and 87 community groups were created to manage the mangroves.

Workforce function

All sectors can deploy NbI for benefits to their workforces.

Efficiency and productivity

Studies have shown that NbI can increase the cognitive functioning, attention span and motivation of employees, and can result in increased productivity and efficiency at work. Contact with urban nature has been linked to greater ability to cope with life stressors, improved work productivity and reduced job-related frustration, increased self-esteem, and enhanced capacity to pay attention (Sturm and Cohen 2014). NbI can improve performance through employee satisfaction and can aid in productivity improvements and long-term profits, as demonstrated in the case of hotel workforces (Yu et al. 2020).

Staff retention and loyalty

Studies point to the benefits that NbI can provide in terms of workforce loyality (e.g. Han and Hyun 2018). For example, businesses in Glasgow, Scotland, which were located next to newly regenerated green space, had better staff retention and morale (GMCA 2019).

Mental health benefits

The deployment of NbI across infrastructure sectors can improve the mental health and emotional well-being of workforces (Han and Hyun 2018), and increase job satisfaction and performance (Yu et al. 2020). Nature can provide a calming environment, reduce stress, reduce burnout and fatigue, increase physiological and psychological relaxation, and lead to employees who are more engaged at work (Elsadek et al. 2019; Han and Hyun 2018; Nejati et al. 2016).

Physical health benefits

NbI can lead to improved physical health outcomes for employees. For example, NbI can improve thermal comfort, air quality, provide opportunities for exercise, and support the provision of nutritious food. A study reported that workers in an office with foliage plants reported fewer physical symptoms, including coughing, hoarse throat and fatigue, than when no plants were present (Fjeld 2000).

Multiple additional benefits

This study finds that all sectors can integrate NbI for the provision of multiple additional benefits for the environment, the economy, and society.

Environment

The development of NbI can result in multiple benefits for the environment and biodiversity. These include:

Improved ecosystem connectivity

NbI can lead to improved ecosystem connectivity and reduced fragmentation, a factor that underpins biodiversity (Key et al. 2022). For example, through investment in NbI, infrastructure practitioners can help to create ecological networks that can facilitate the safe movement of wildlife and genetic diversity (World Bank 2021). This includes the development of ecological corridors along networked infrastructure such as roads, railways and waterways. It also includes the connection of smaller green spaces, such as networks of green roofs, gardens, and urban parks, with larger green spaces, such as forests and grasslands, elsewhere in the region.

Habitat

NbI can increase the prevalence of habitat for various species through the protection, restoration, improved management and creation of terrestrial and marine ecosystems (World Bank 2021). For example, in the Philippines, Manila Water Company, Inc., which provides water supply, wastewater and sanitation services, has invested in large scale catchment efforts to improve water quality and reduce the impact of soil erosion on water supplies during heavy rainfall and typhoons. In partnership with the Metropolitan Waterworks and Sewerage System (MWSS), Department of Environment and Natural Resources (DENR), multiple local government units (LGUs), indigenous people and other stakeholders, they have reforested native tree species and helped to protect 171,901 hectares within the watersheds of General Nakar, Ipo, La Mesa, Pan as Hayiban and Villa Maria (Manila Water 2022).

Species diversity

Through the deployment of NbI, infrastructure practitioners can help to maintain or enhance the genetic diversity of species. This can be achieved through protecting or restoring native ecosystems, and by facilitating the movement of biodiversity through connected ecosystems. For example, conventional snow fences act as a physical barrier that can disrupt the movement of wildlife, whereas living snow fences can facilitate the continued movement of wildlife, and at the same time provide aesthetic value to people (Blanken 2018).

Air pollution

The deployment of NbI can provide benefits to infrastructure and at the same time support the reduction of pollution arising from different infrastructure sectors and the wider environment (Choi et al. 2021). Trees and vegetation can absorb gaseous pollutants through their leaf surfaces and intercept dust, ash and pollen, at the same time releasing oxygen through photosynthesis. By moderating local air temperatures, they can reduce the frequency of conditions in which ground-level O_3 forms (Millward and Sabir 2011). In cities, urban parks are reported to filter up to 85% of air pollution (Browder et al. 2019).

Land and water pollution

Use of NbI can help to reduce the pollution of the local terrestrial and marine environment resulting from infrastructure systems. For example, vegetation, such as wetlands, can assimilate pollutants and toxins. The use of phytocaps on landfill within the solid waste sector can prevent the movement of pollutants from landfills from filtering into the local environment (Lamb et al. 2019; Khapre et al. 2019). The use of grazing programmes instead of mechanized maintenance within airports is reported to remove the need for pesticides that can pollute local water systems (AT 2016).

Carbon

Depending on factors such as ecosystem type, species, and management practices, NbI can sequester and store carbon dioxide. For example, reduced deforestation and degradation is considered a major strategy to reduce GHG emissions (IPCC 2019). Grasslands store over 10% of terrestrial biomass carbon and could sequester one billion tons of carbon annually if sustainably managed (Chausson et al. 2020). Peatlands store more than 30 Gt of carbon globally, which is more than twice the amount of the world's forests (UNEP 2021). Mangroves sequester approximately three to five times as much carbon per unit area compared to terrestrial forests (Opperman et al. 2021). Improved agricultural management practices are also found to have mitigation potential (IPCC 2019).

Economic

Well-planned NbI can result in various economic benefits. These include:

Tourism

The benefits that NbI can provide in terms of aesthetic value, biodiversity and recreation can lead to economic benefits through tourism. For example, while street trees can provide benefits to roads through acting as a buffer between vehicles and pedestrians, those that bloom seasonally can also attract seasonal tourism (World Bank 2021), as demonstrated in the case of Japanese cherry blossom trees. Coral reefs can protect infrastructure from coastal hazards and at the same time can increase the number of tourists travelling to countries for diving (Spalding et al. 2017). Mangroves can prevent coastal erosion and simultaeously increase opportunities for ecotourism – such as the mangroves in Kenya, located predominantly in Lamu Country and the Tana River Delta, that provide ecotourism benefits as well as supporting bee farming, aquaculture and fisheries (Opperman et al. 2021). It is reported that countries with global biodiversity hotspots have higher annual growth of tourism investments than other countries (Blicharska et al. 2016).

Increased property values

Certain NbI, such as an urban park or nature reserve, can increase the attractiveness of an area and lead to increased property prices (Ommer et al. 2022). It is reported that the increase in property prices can be as much as 5-20% (Kapos et al. 2019; Bockarjova et al. 2020).

Marketable resource provision

NbI can support the production of marketable natural resources, such as fish, crops, and timber, which can provide economic benefits to people in the local community in which they are produced and have wider economic benefits through production chains (Kapos et al. 2019; World Bank 2021; UNEP 2014). For example, floodplains can protect infrastructure systems from river flooding and simultaneously provide critical spawning and rearing habitat for fish that ultimately end up in freshwater fisheries (Opperman et al. 2021). Coastal ecosystems, such as coral reefs, seagrass and mangroves, underpin marine fisheries. The deployment of grazing lands under overhead transmission infrastructure can enhance the transmission of energy and at the same time facilitate the rearing of livestock, which support millions of people, including poor and marginalized groups (Chausson et al. 2020). The use of commodity trees as part of agroforestry systems and shelterbelts can reduce erosion and sedimentation of water-based infrastructure systems while generating additional income for local communities (Browder et al. 2019).

Local investment and spending

The deployment of NbI can attract businesses to an area and lead to increased investment. For example, in Finland, natural ecosystems have been found to improve the local landscape, increase people's enjoyment of an area, and attract businesses, which in turn can attract customers, employees and further services (Venn and Niemela 2004). NbI can also lead to increased spending in local businesses. For example, street trees can simultaneously protect roads from the impact of heat and lead to increased spending in local restaurants and cafes, increasing restaurant patronage by 30% on weekdays and 50% on weekends (Treeconomics and Green Blue Urban 2018).

Jobs

As with built infrastructure options, the development of NbI can lead to the creation of jobs for local communities across the lifecycle of NbI (World Bank 2021; Kapos et al. 2019). Human resources are required for the planning, design, implementation, maintenance, management and monitoring of NbI. Policies to promote women's involvement in NbI-related jobs can help to promote gender equality in the workforce and help ensure that women's service needs are being met through infrastructure development.

Social

The careful design and development of NbI can result in multiple benefits for societies. These include:

Food production

In many cases, NbI can support the provision of food resources to local communities. For example, the protection, restoration and improved management

of forests can play a key role in the provision of natural food resources such as fruit, mushrooms, and animals (World Bank 2021; IPCC 2019). It is reported that wild harvested meat and freshwater fish provide between 30% and 80% of protein intake for many rural communities (IPCC 2019). Green roofs can support the provision of food, which can offer additional benefits through supporting small agricultural businesses and reducing the distance that food must travel from producers to consumers (World Bank 2021). Through the deployment of NbI, infrastructure practitioners can help to maintain a diversity of pollinators, which can ensure the pollination of crops, of which 35% of global food production depends upon (Blicharska et al. 2016; Kapos et al. 2021; World Bank 2021). Because of the important role they play in food production in developing economies, it is important that women's inputs and knowledge are accounted for when considering the impacts of NbI on local food production.

Natural resource provision

NbI can support the provision of natural resources that are used by local communities. These include natural medicinal resources, vegetables, fish and meat products for domestic consumption. For example, Lukanga Swamp in Zambia protects water supplies to hydropower and also acts as a crucial resource for local communities who use it for fishing, hunting and charcoal production (Opperman et al. 2021).

Aesthetic value

NbI along infrastructure networks such as railways can provide a natural screen around built infrastructure, which provides aesthetic value (Blackwood et al. 2022; Anderson et al. 2022). Green roofs and walls can protect infrastructure in cities from floods and heat while providing aesthetic benefits to local inhabitants (Choi et al. 2021). This can make areas more attractive to residents (World Bank 2021) and increase public acceptance of infrastructure (Anderson et al. 2022; Browder et al. 2019).

Noise reduction

NbI, such as the creation of green corridors, can work as buffers that shield people from the noise of large-scale infrastructure (World Bank 2021). A study of roadside vegetation in Sri Lanka found that it can lead to an average reduction of road traffic noise of four decibels, and a 40% reduction in average acoustic energy (Kalansuriya et al. 2009). Living walls in cities can reduce noise pollution between one and ten decibels (Enzi et al. 2017). The extent to which green spaces reduce noise pollution depends on factors including the quantity, quality and distance from the source.

Social cohesion

The engagement of local communities across the lifecycle of NbI projects, through the planning, design, and maintenance of NbI, can increase community cohesion (World Bank 2021). Green spaces can also improve social cohesion through providing areas for social gathering. This can increase the ability of residents to interact positively and foster a sense of community (Cohen et al. 2008; Kim and Kaplan 2004).

Crime

NbI have been associated with lower incidences of crime in several studies. For example, in Baltimore, USA, Troy (2012) found a 1.2% decrease in crime levels for every 1% increase in tree canopy. Equally, in Vermont, a study found that a 10% increase in tree cover equates to approximately 12% reduction in crime. The presence of trees is considered to increase the use of public space, enhance surveillance, and potentially serve as a symbol of neighbourhood social control if they are well-cared for (Donovan and Prestemon 2012). However, the crime reduction benefits of NbI are likely to vary – for example, the presence of smaller trees on private land may increase crime incidence, as criminals can use them to hide behind and avoid detection.

Women

In many countries, women play a central role in the management and protection of natural resources (Browder et al. 2019). NbI can improve gender equality through the participation and involvement of women across the lifecycle of NbI projects, from planning and design to implementation and maintenance. At the same time, the integration of women and their unique knowledge on local ecosystems can increase the effectiveness of NbI projects.

Indigenous communities

Indigenous people represent 5% of the population but steward approximately 22% of land globally and protect almost 80% of global biodiversity (UN 2018; IISD 2022b). The lives of indigenous communities are deeply intertwined with natural ecosystems - their livelihoods, traditions, culture and identity depend upon nature (Salmon 2000; Garnett et al. 2018; Seddon et al. 2021). Consequenty, the loss and degradation of natural ecosystems disproportionalty affects indigenous communities (IISD 2022b). Through deployment of NbI, infrastructure practitioners can help to safeguard the natural landscapes that indigenous communities rely upon. Indigenous communities should be fully integrated across the lifecycle of NbI projects, from planning and design, to management and maintenance, and should maintain ownership over their natural landscapes long-term.

Infrastructure investments can help to realize many of the benefits outlined above. The potential for NbI to provide so many additional benefits to the environment, economies and societies should be a driving factor in prioritising NbI over built infrastructure options in decisions on infrastructure and scaling their uptake across countries (Browder et al. 2019).

The risk of overlooking nature in decision-making

The previous subsections highlight the multiple and complex ways that NbI forms an integral part of the overall infrastructure system. One implication of this is that, when their role in the provision of infrastructure services is overlooked - due to undervaluation of the enhance function, for example - the resulting ecosystem degradation can increase risks to the services upon which our societies and economies depend, especially from natural disasters. This challenge is magnified by ecosystems' sensitivity to the dual threats of climate change and biodiversity loss (Malhi et al. 2020). For example, within the hydropower subsector, high sedimentation resulting from catchment degradation has been shown to lead to lost reservoir water storage capacity totalling 10-15% over three decades along the Tana River in Kenya (Jain et al. 2020), which increases the vulnerability of the Kenyan energy sector to drought.

Through systematic consideration of the ways in which NbI can provide benefits, practitioners can both improve the provision of infrastructure services and help to ensure that natural ecosystems continue to persist, function, and continue their capacity to provide multiple benefits in the long-term.

Case study:

The "ridge-to-reef" approach to deliver multiple benefits in Port Salut, Haiti (UNEP)

Location:
Port Salut, Haiti

Source:
Network Nature (n.d.)

The Municipality of Port Salut in Haiti is densely concentrated near the shore in the country's South Department. Many of the 18,000 inhabitants have mixed livelihoods, relying on both fishing and subsistence agriculture, while tourism is also a growing industry. However, the Municipality is vulnerable to coastal hazards, and requires a range of socio-economic services and opportunities to safeguard the mixed livelihoods.

In partnership with the National Government, the Municipality of Port Salut, and local partners, UNEP and the European Commission implemented a pilot demonstration project on ecosystem-based disaster risk reduction in Port Salut. The project used a "ridge-to-reef" approach to demonstrate the effectiveness of NbS in mitigating the risk of coastal hazards, preserving biodiversity and delivering a range of other benefits. This approach targets both environmental degradation in the uplands ("ridge") and protecting or restoring marine ecosystems ("reef") for holistic interventions and benefits in communities.

The project resulted in more than 140 hectares of reforestation in areas exposed to coastal hazards and flooding. To support these activities, a tree nursery was established, producing 137,000 seedlings of coastal and riparian species and fruit trees, directly benefiting 200 households. In the upland watersheds, sustainable vetiver farms were established on 6.5 hectares to demonstrate effective soil erosion control on hillsides and reduce sedimentation rates downstream, as well as associated siltation and pollution at the coast. Finally, the project also focused on creating sustainable fisheries, while incorporating participatory action planning, shelter creation, boat improvement, and safety training. The wider socio-economic benefits from the NbS therefore include creation of green jobs, increased sense of community ownership and social inclusion.

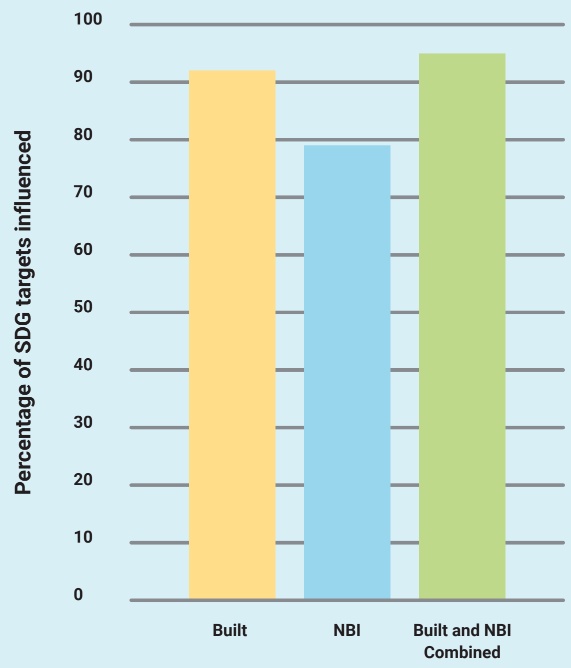
The benefits of NbI for addressing global challenges

Sustainable Development Goals

Nature is only explicitly mentioned in two SDGs (SDG 14 – 'life under water', and SDG 15 – 'life on land'); however, it is recognized to offer broader potential to influence the SDGs (Blicharska et al. 2016). This report assessed the eight infrastructure sectors that Thacker et al. (2019) found could influence 92% of SDG targets (civic, digital communications, education, energy, health, solid waste, transport, and water), and finds that NbI can influence up to 79% of SDG targets across all 17 SDG Goals *(see Figure 2)*, including four targets that were not considered to be influenced by built infrastructure *(see Table 3)*. When NbI solutions are combined with built infrastructure assets, infrastructure systems can have greater cumulative impact on the SDG targets than either built infrastructure or NbI can alone, influencing up to 95% of SDG targets. This points to the importance of strategically planning integrated infrastructure systems for achieving the maximum possible progress on the SDGs.

The importance of integrating NbI with built infrastructure for greater progress on the SDG targets is more prevalent when considered at the level of individual sectors – this report finds that if NbI is deployed strategically as part of infrastructure systems, infrastructure in a single sector could influence 24%-47% more SDG targets compared to the use of built infrastructure alone in that sector *(see Figure 3)*, depending on the sector. This is owing to the ability of NbI to provide multiple additional social, environmental, and economic benefits in addition to the primarily intended infrastructure service. This shows that practitioners in different infrastructure sectors could contribute to a greater extent towards meeting the national policy objective of the SDGs if they incorporate NbI into infrastructure plans and designs. It also points to the importance of assessing the additional benefits that NbI can provide so that they can be included in cost-benefit analyses of different infrastructure solutions - something that is not consistently done today. By undervaluing these additional benefits, such as for carbon sequestration and the reversal of ecosystem degradation, decision-makers risk missing targets under the SDGs, Paris Agreement and the CBD.

Figure 2. The influence of built infrastructure versus NbI on the SDG targets



A study by Fuldauer et al. (2022) found that climate adaptation of infrastructure systems is necessary to safeguard progress on all SDG targets. This report finds that decision-makers could incorporate NbI into the adaptation of infrastructure systems to safeguard progress on all SDG targets while at the same time helping to reverse the loss of nature and biodiversity. As such, strategies developed in pursuit of sustainable development should look to integrate NbI to both advance and safeguard progress across environmental, social, and economic targets under the 2030 Agenda for Sustainable Development.

Climate adaptation

Increased flexibility and adaptability

Beyond contributing to the adaptation of infrastructure systems, NbI can lead to broader benefits for adaptation and resilience. Some NbI are more flexible and adaptable to climate change than conventional built infrastructure solutions, and therefore more resilient to climate impacts (Chazdon et al. 2007; Seddon et al. 2020; Moos et al. 2018). For example, some coastal ecosystems can adjust to sea level rise through processes including sediment accretion and landward shift (World Bank 2016; Zhai 2019). Mangroves have been found to be able to keep pace with moderately high rates of sea level rise through vertical accretion (Krauss et al. 2013; Menendez et al. 2020), and vegetated dunes can accumulate sediment, allowing them to grow and be more adaptable to endure coastal erosion (Feagin et al. 2015; Word Bank 2021). In contrast, built coastal defence infrastructure assets, such as sea walls, need continual heightening and widening to keep up with sea level rise (Tiggeloven et al. 2022).

Increased system-wide resilience

The deployment of NbI within each infrastructure sector can support the resilience of other infrastructure sectors. For example, the use of constructed treatment wetlands for water treatment and reuse in the energy sector (e.g. for cooling in thermal power plants) can increase the resilience of the water sector by reducing pressure on other water supplies. Similarly, the use of green walls and green roofs in the building sector can provide thermal insulation and reduce requirements for heating or air conditioning, leading to reduced pressure on local energy networks.

Equally, by strategic deployment of NbI to protect key infrastructure assets, practitioners can safeguard accessibility of, and delivery of services by, infrastructure assets in other sectors. For example, by deploying NbI to protect transportation infrastructure networks from floods, practitioners can safeguard access to infrastructure assets such as hospitals and the delivery of healthcare services, and protect supply chains for essential goods.

Decision-makers can therefore magnify the benefits for adaptation and resilience from local to national scales, and potentially across country borders, by developing integrated NbI strategies across multiple infrastructure sectors.

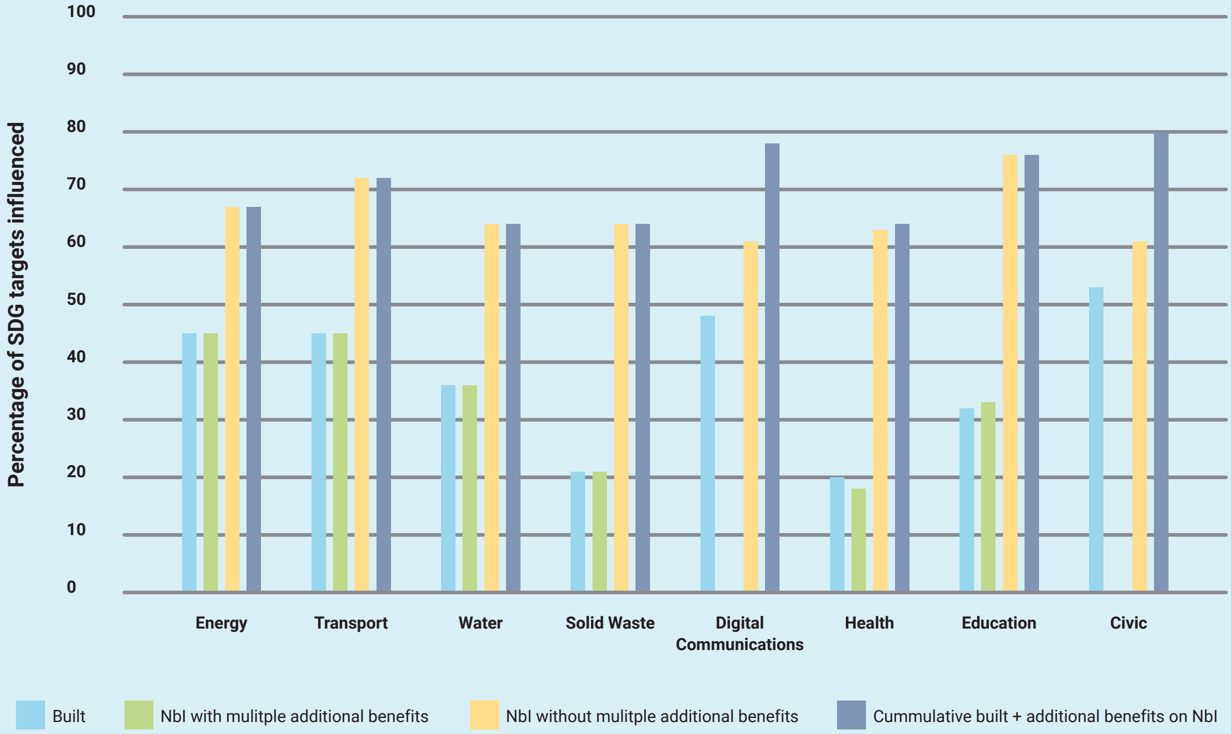
Resilient workforces

Climate change is recognized by the World Health Organization (WHO 2021) as the biggest global health threat. The deployment of NbI across sectors can lead to increased physical and mental resilience of workforces, which are critical to the provision of infrastructure services. NbI can improve air quality, reduce heat, and help to regulate the local environment in which they work. It is expected that companies will face increasing legal and regulatory requirements

Table 3. Targets that can be influenced only by NbI and not by built infrastructure across the eight infrastructure sectors considered by Thacker et al. (2019). Based on evidence from Blicharska et al. (2016); Fuldauer et al. (2022) and Thacker et al. (2019).

<table>
<tr><th>Target</th><th>Description</th><th>Justification</th></tr>
<tr><td>15.9</td><td>By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.</td><td>Influenced via services including environmental education and value for scientific research.</td></tr>
<tr><td>15a</td><td>Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems.</td><td rowspan="3">Environmental education: better understanding of ecosystems helps makes the case for increasing financial resources to conserve them.</td></tr>
<tr><td>15b</td><td>Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.</td></tr>
<tr><td>17.3</td><td>Mobilize additional financial resources for developing countries from multiple sources.</td></tr>
</table>

Figure 3: Percentage of SDG targets influenced by infrastructure with and without built infrastructure with and without the mulitple additional benefits of nature



to support occupational health in response to climate change. The California Division of Occupational Safety and Health (OSHA, n.d.) has established the California Illness Prevention Standard (n.d.), which legally requires employers in infrastructure sectors such as energy and construction to provide access to shade in order to reduce the impact of extreme heat on employees. NbI can also help to relieve mental stress and anxieties associated with climate change (Mind 2021). By recognizing the potential for NbI to provide these benefits, infrastructure decision-makers can help to ensure that their employees are resilient in the face of climate change, and able to perform their jobs.

Multiple additional adaptation benefits

NbI can result in wider adaptation benefits by reducing the degree to which individuals, communities and societies are affected by climate impacts (Seddon et al. 2021). These include:

- **Economic resilience:** income diversification is considered a major adaptation strategy and form of risk management (IPCC 2019). NbI can diversify income streams through the provision of natural resources and job opportunities (Kapos et al. 2021). This can result in economic benefits to local communities, which can help to smooth out fluctuations in income streams that underpin livelihoods, and lead to improved financial security and increased options for coping with climate change impacts when crops or other sources of income fail (IPCC 2019). NbI can also create economic benefits through increased cost savings, cost-effectiveness, and avoided economic damage to infrastructure networks from climate change. Specific efforts to ensure women and those from other marginalized and vulnerable groups benefit are crucial.

- **Societal resilience:** NbI can provide food and other natural resources that can act as a safety net for communities in the face of increased climate variability (Blicharska et al. 2016), and during times of food insecurity (IPCC 2019).

By supporting the provision of basic services, such as energy, water, education, and health and well-being, and generating multiple additional benefits, NbI can provide additional positive outcomes that can improve societal resilience. The benefits of NbI to societal resilience are particularly important in the global south where dependency on local natural resources for food and income is high (ibid.), and for women and vulnerable segments of the population.

- **Environmental resilience:** the resilience of ecosystems is key to the success of NbI and to ensuring the persistence of natural ecosystems as global temperatures rise and the frequency and severity of climate impacts increase. Infrastructure practitioners can increase the resilience of ecosystems by improving ecosystem health, such as through increasing habitat connectivity and species diversity (Key et al. 2022). Through the restoration of native, diverse ecosystems, NbI can support pollination services, protect ecological networks and increase the resilience of biodiversity.

- **Resilience of indigenous communities:** the loss and degradation of natural ecosystems, including through climate change, impacts the well-being, culture, and livelihoods of indigenous people, whose lives are deeply intertwined with nature. By safeguarding natural ecosystems and embedding the needs and values of indigenous communities into NbI designs, practitioners can help to increase the resilience of indigenous people to climate change. The New Zealand Government is progressive in their attempts to include indigenous values and needs in their first National Climate Change Risk Assessment (NCCRA) – it does this by combining the indigenous Māori and their world view, 'Te ao Māori', which acknowledges their 'interconnectedness and interrelationship of all living and non-living things, their vital connection with and reliance on the natural world', with scientific, technical and expert analysis (New Zealand, Ministry for Environment 2020). The NCCRA specifically highlights the 'risks to Māori social, cultural, spiritual, and economic well-being from the loss of species and biodiversity due to greater climate variability and ongoing sea level rise' (ibid). It identifies specific risks, opportunities and gaps that have particular relevance to Māori rights, values, practices and communities, and embeds Māori knowledge in the development of appropriate adaptation responses (ibid.).

Climate mitigation

It is widely understood that many ecosystems can capture and store carbon, and therefore contribute to limiting global temperature increase as defined in the Paris Agreement (IPCC 2019; UN 2015). The IPCC Climate Change and Land Report found that all scenarios consistent with the 1.5°C temperature target rely on land use mitigation strategies in addition to decarbonization (IPCC 2019). The 27th Conference of the Parties (COP) to the Paris Agreement included the term 'nature-based solutions' within the COP cover decision text, reflecting their importance for mitigation outcomes, as well as adaptation. The deployment of NbI can therefore contribute to the mitigation component of the Paris Agreement via the protection and restoration of natural carbon sinks, the better management of natural landscapes and the creation of new natural sinks through NbI such as urban parks, green roofs, and green walls.

A study by Roe et al. (2021) found that the majority of the potential cost-effective (available up to US \$100/tCO_2eq) land-based mitigation (which totals 8-13.8 GtCO_2eq per year between 2020 and 2050) is located in developing countries and least developed countries. This correlates with the countries where infrastructure investment needs are greatest (UNEP 2022a). It is therefore critical that decision-makers in these regions prioritize the use of NbI, which can contribute to meeting local development needs whilst at the same time maximizing the protection of these valuable carbon sinks.

It is important to note that commitments and actions on NbI cannot replace the urgent need for decarbonization of all infrastructure sectors (Seddon et al. 2020). However, this report finds that NbI has a potentially larger role to play in national mitigation strategies than just carbon sequestration and avoided land use change:

- Through the substitution of built infrastructure assets, NbI options can remove or reduce GHG emissions embedded within the built infrastructure lifecycle, including materials, transportation, construction, operation, maintenance, and decommissioning. For example, the protection and restoration of mangroves, coral reefs, seagrass and beaches can remove the need for built assets such as sea walls and their embedded emissions.

- By complementing built infrastructure assets, NbI can help to reduce emissions embedded within the maintenance of built infrastructure, including through reduced requirements for dredging, mowing, and embedded within inputs such as flocculants. For example, wetlands are less energy intensive than traditional water treatment options, and therefore lower emissions associated with energy use (WWAP 2018).

- By protecting built infrastructure assets, NbI can extend the lifespans of built infrastructure components, and reduce the frequency at which they are maintained and repaired, leading to reductions in associated emissions. For example, green roofs implemented across Chicago O'Hare airport have been found to double the lifespan of the roof, and therefore reduce the frequency at which they are repaired and replaced (AT 2016).

Biodiversity

The 15th Conference of the Parties to the UN Convention on Biological Diversity resulted in a new global framework to halt and reverse global loss of nature, termed the Kunming-Montreal Global Biodiversity Framework (GBF COP15). This includes four long-term goals to be achieved by 2050, and 23 targets for urgent action to be achieved by 2030 (Convention on Biological Diversity [CBD] 2022).

This report finds that NbI can play a critical role in achieving the GBF, and can contribute to meeting three of the four long-term goals and 70% (16) of the targets. *Table 4* shows the influence of NbI on the goals and targets of the GBF, respectively.

Key areas where NbI can contribute to the achievement of the GBF of the Convention of Biological Diversity are discussed below:

- **Embedded biodiversity values in spatial infrastructure planning:** by embedding consideration of NbI into infrastructure planning, design and implementation across all sectors as part of standard practice, practitioners can support achievement of targets including 1, 11, 12 and 14 of the GBF. The strategic planning and deployment of NbI, including in urban areas such as cities, can help to address land use change, provide benefits to societies, increase ecological connectivity and advance progress on national strategies including poverty eradication.

- **Reversed loss of nature:** through deployment of NbI alongside built infrastructure, and prioritization of NbI where possible, decision-makers can make a significant contribution to ensuring that development and adaptation of infrastructure systems does not add to the loss of natural ecosystems, and instead contributes to their protection, restoration, and improved management. This can bring about benefits that directly advance several of the targets of the GBF, including targets 2, 3, 9 and 10.

- **Reduced pollution of nature from infrastructure:** by scaling the uptake of NbI within infrastructure, practitioners can reduce pollution from infrastructure on natural ecosystems and biodiversity, and contribute to target 7 of the GBF. This includes through implementation of improved agricultural management practices that can stabilize soils and prevent contamination of water supplies with nutrients from agricultural runoff, the assimilation of pollutants through watershed restoration, and the creation of phytocaps in the closure of landfill to reduce contamination of the environment with leachates.

- **Increased biodiversity health and resilience:** the use of NbI can increase the health and resilience of natural ecosystems and biodiversity and contribute to targets 4, 6 and 8 of the GBF. For example, as outlined above, through use of native species and improved management actions, such as weeding and invasive species removal, practitioners can help to increase genetic diversity and minimize the impact of alien species on natural ecosystems, and improve the resilience of natural ecosystems to climate change.

Case study:

Landslide remediation based on tree-planting in Sugarloaf Mountain, Sierra Leone (UNOPS)

Location:
Sierra Leone

Source:
UNOPS (n.d.) and Sierra Leone, Ministry of Finance (2018)

In August 2017, Sugarloaf Mountain, located on the outskirts of Sierra Leone's capital of Freetown, collapsed after days of torrential rain. This resulted in a tidal wave of mud, floodwater, boulders and trees, which buried and destroyed homes and businesses in the Freetown neighbourhood of Regent. More than 1,100 people were reported killed or missing. The landslide also destroyed schools, bridges, healthcare facilities and other essential infrastructure, causing an enormous amount of economic loss across sectors. A World Bank report estimated that the total economic value of the disaster amounted to approximately US $31.65 million in US dollars.

In response, UNOPS undertook landslide remediation work (stabilizing unstable ground) with funding from the World Bank and the government of Sierra Leone to make the area safer as survivors return. Engineers and geologists used drones and 3D imagery to better understand the nature of the landslide area from a safe distance, collecting information needed to determine how to stabilize the area. Following this exercise, five watercourses were rebuilt and 10,000 trees were replanted as a solution to help stabilize the soil and provide a source of food and income. Further complementary activities included debris management, human remains removal, contractor management, and stakeholder coordination and engagement.

Additional trees will be revegetated in order to promote the sustainability of the slope, which is important for future development of different forms of infrastructure and socio-economic activity. Those trees will be managed by local communities to provide food and medicine, including fruits, nuts, seeds, kernels and leaves. It will also allow the local communities to promote the growth of species listed on the IUCN's Red List of Threatened Species. The local community provided much of the labour for the project and received training in forestry and tree husbandry. The combination of project activities demonstrates the potential of NbI for (re)building resilience across systems.

© Unops

Table 4. The influence of NbI on the GBF goals

Target	NbI Influence
A	X
B	X
C	
D	X
1	X
2	X
3	X
4	X
5	X
6	X
7	X
9	X
9	X
10	X
11	X
12	X
13	
14	X
15	
16	X
17	
18	
19	X
20	
21	
22	X
23	

- **Increased awareness and education on the value of nature:** by embedding NbI into development, adaptation and mitigation strategies across infrastructure sectors, infrastructure practitioners can support progress on target 16 of the GBF. Previous sections of the report highlighted the benefits of scaling uptake of NbI within the education sector in terms of increased emotional connections to nature and pro-environmental behaviours (Kuo et al. 2019). Deployment of NbI across the lifecycle of infrastructure projects can also serve to raise awareness of the importance of nature and sustainable development choices amongst infrastructure practitioners and potentially support the formation of similar emotional connections to nature within sector workforces.

- **Benefits to indigenous people, women and children:** multiple targets include references to indigenous communities. Good practice on NbI should embed indigenous and local communities, including women (who often have responsibility for natural resource management), across the lifecycle of projects, from planning and design to implementation, monitoring and management. Consequently, deployment of NbI should advance progress on multiple targets of the GBF, including targets 1, 3, 5, 19 and 22. Further information on the benefits of NbI to indigenous communities and women are discussed in the sections above.

- **Increased financial flows to nature:** investment in NbI can contribute to target 19 of the GBF by helping to increase financial flows from infrastructure into the protection and restoration of natural ecosystems. The section below on 'closing the infrastructure and nature financing gaps' provides further information on the benefits that NbI can provide in terms of leveraging finance for nature from multiple sources.

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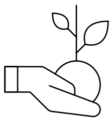
Synergized progress on multiple global policy agendas

NbI is the only type of infrastructure that can contribute to mutual, synergistic progress on the SDGs, Paris agreement, and GBF. As countries set commitments and implement actions towards the achievement of national policy agendas, through Nationally Determined Contributions (NDCs), National Adaptation Plans (NAPs), National Development Plans (NDPs) and National Infrastructure Plans (NIPs), there is a both a major need to and a huge opportunity to strengthen the contribution of NbI. This can enable countries to increase benefits from the same investment and ensure that actions towards one policy agenda do not undermine actions towards another.

The cost-effectiveness of NbI

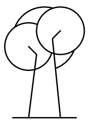
A growing body of evidence is showing that NbI can be both lower cost and more cost-effective solutions compared to built infrastructure options. Illustrative examples are outlined below, considered through the lens of the five functions.



Deliver Function

Through the substitution of built infrastructure assets, NbI can remove the need for investment in built infrastructure options. For example, New York City's Working Forests Pollution Prevention programme, which implemented forest protection and improved agricultural management to reduce pollution within the freshwater supply, removed the need to build a water treatment plant that would have cost US $8-10 billion. Equally, in Portland, Maine, the services provided by healthy forests removed the need for investment in a new water treatment plant – this saved US $97-155 million over two decades (Hallegatte et al. 2019). Studies report that the peak flow regulation and soil stabilization services provided by forests save water treatment companies across the world's largest cities as much as US $890 million per year (McDonald 2014; Kapos 2019). Within the health sector, the preventative health services provided by natural ecosystems can lead to reduced expenditure needs. For example, it has been estimated that in England, UK, the National Health Service (NHS) could save £2 billion annually in healthcare treatment costs if all people had access to good quality green space (Government of the United Kingdom Environment Agency 2020).

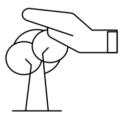
Correspondingly, the loss of nature's services can increase infrastructure costs. It is estimated that the degradation of watersheds costs cities globally US $5.4 billion per year in water treatment costs and impacts the drinking water of more than 700 million people (Tremolet and Karres 2020; Browder 2019; UNEP 2014). Globally, annual costs to replace lost reservoir storage capacity due to sedimentation, in the form of constructing new or raising existing dams, are estimated at US $10-20 billion (Tremolet and Karres 2020; Browder 2019; UNEP 2014).



Enhance Function

The design of integrated infrastructure systems that use NbI to enhance the functioning of infrastructure assets can generate multiple cost savings across the sectors in which they are implemented. For example, the Life Elia project demonstrated how NbI, such as the restoration of peatlands and other low-lying habitats under power lines, can lead to reduced infrastructure maintenance costs. This project was shown to break even in three-12 years and become as much as 1.4-3.9 times cheaper, depending on the NbI, than traditional maintenance methods after three decades (European Commission 2019; Life Elia 2021; Life Elia n.d.). Within the finance sector, forest-based NbI have been shown to reduce residential insurance premiums by 41% in areas at risk of wildfire in Sierra Nevada (CISL 2022). Also within the finance sector, the cost of the protection of coral reefs along Mexico's coasts through catastrophe insurance is between US $50,000-150,000, lower than built infrastructure alternatives, such as seawalls, which total one million US per half mile (CISL 2022).

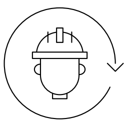
NbI can reduce sedimentation of water and the need for maintenance in the form of dredging (UNEP 2014; WWAP 2018). The Nature Conservancy estimates that a 10% reduction in sediment can reduce operation and maintenance costs of water companies by 2.6%. Vogl et al. (2016) report that annual operation and maintenance costs in India are estimated at 5% of capital costs for hydroelectric facilities with high sediment inflows, compared to 1-4% under normal conditions. Similarly, a 4% reduction in energy efficiency of energy generation is reported during monsoon flows with high sediments at the 12MW Jhimruk hydropower plant in Nepal. Equally, forest-based NbI have reduced river siltation in Costa Rica and resulted in lower dredging requirements (Ozment et al. 2021).



Protect Function

There is evidence to suggest that the protective services of NbI can be lower cost than built infrastructure alternatives (Kapos et al. 2019) and lead to multiple cost savings. For example, it is reported that living snow fences are up to 90% cheaper to install and maintain than slatted snow fences (Arbor Day Foundation, n.d.). Narayen et al. (2016) estimate that the restoration of coastal ecosystems can be two to five times cheaper than built infrastructure across 52 coastal defence projects in the US, while mangrove projects in Vietnam can be three to five times cheaper than built breakwater infrastructure. Ferrario (2014) found that the construction of structural coral reefs can reduce wave heights by a comparable amount to that of built breakwaters (51-74% wave height reduction for coral reefs and 30-70% for breakwaters), but their construction cost is less than 10% of breakwater cost (median project cost of US $1,290/m and US $19,791/m, respectively). In this case, NbI can increase in cost-effectiveness in locations that have higher water depths, as breakwater construction increases in cost in deeper water.

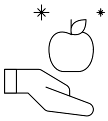
The potential for NbI to protect infrastructure, societies and economies from climate impacts can lead to further economic benefits through avoided damages. For example, mangroves and reefs in the Philippines have been shown to prevent more than US $1 billion in annual disaster losses (Hallegatte et al. 2019). Chicago O'Hare airport has created more than 338,000ft^2 of green roofs across 12 airport buildings - these are able to retain up to 90% precipitation (2 million gallons of stormwater annually), which help to double roof lifespans and save the airport US $1.5 million in re-roofing costs (AT 2016). Mangroves cost around US $1 million per year, but are estimated to save US $7 million in annual dyke maintenance (UNEP 2014).



Workforce Function

The services that NbI can provide to workforces can contribute economic benefits to infrastructure sectors. For example, Elzeyadi (2011) found that employees who had a view of trees and natural landscapes took an average of 16% less sick leave per year, compared to those with no view of nature, leading to cost savings of more than US $2,000 per employee. Equally, NbI can lead to increased productivity of workforces (Sturm and Cohen 2014), which in some cases may lead to economic benefits for the sector.

The potential for NbI to provide various additional benefits, such as for the environment, livelihoods, gender equity, property values and tourism appeal, can lead to wider economic benefits and economic resilience (Kapos 2019). For example, coral reefs are estimated to provide US $36 billion per year in economic value through services to tourism (Spalding et al. 2017). A study in the Dutch city of Utrecht found that property prices in areas of nature-based interventions can be up to 20% higher than areas without (Bockarjova et al. 2020).



Multiple Additional Benefits Function

NbI can also impact countries' creditworthiness, default probability and the cost of capital (CISL 2022). The University of Cambridge found that across 26 countries, the loss of ecosystem services could increase annual interest payment on debt by up to US $53 billion per year, which can leave many developing nations at risk of bankruptcy (CISL 2022). Prioritization of NbI over built infrastructure options will be critical to supporting the economic resilience of these countries, and their financial ability to achieve progress on their national targets.

The adaptability of NbI and capacity to provide services can increase over time, unlike built infrastructure assets. The wider benefits of NbI, which built infrastructure assets are unable to provide, can lead to higher benefit-to-cost ratios compared to built infrastructure options. However, these additional benefits are not always fully reflected in the cost-benefit assessments of infrastructure. It is essential that the full value of the multiple wider benefits of NbI - including economic value - are captured and factored into decision-making, to help make the case for investment.

Closing the infrastructure and nature financing gaps

There is an annual investment gap of US $15 trillion[4] that will be needed by 2040 in order to meet the US $94 trillion[5] of infrastructure investment required to meet development needs. At the same time, there is an annual average shortfall of approximately US $330 billion per year in funding for nature by 2030[6] (UNEP 2022b). NbI has untapped, transformative potential to help fill part of the infrastructure and nature financing gaps. Through the provision of multiple services at the same time, NbI can help to optimize the use of funding and support mutual progress towards meeting needs for development, climate change, and biodiversity in a balanced way.

- **US $0.6 trillion per year:** infrastructure investment gap
- **US $330 billion per year:** nature investment gap

NbI offer opportunities to help fill global investment gaps for infrastructure and nature.

There is an additional investment gap of US $3.5 trillion, over and above the US $94 trillion, required to meet the SDGs for electricity, water, and sanitation (Global Infrastructure Hub 2017). At the same time, the water sector accounts for the highest proportion of climate adaptation costs, totalling 54% (Thacker et al. 2019). Current direct investments into nature make up less than 1% of total water sector investments globally (WWAP 2018). Given the applicability of NbI to the water sector, the potential for scaling NbI within the sector is significant and should be reflected in investment decisions.

The largest infrastructure investment gaps have been identified to be in low- and middle-income countries (UNEP 2022a). Investment in NbI can help to alleviate the financial burden of infrastructure investment on developing countries, while at the same time helping to restore and protect natural ecosystems and the indigenous communities who rely upon them.

For adaptation, it is reported that international public finance for nature-based adaptation accounted for 9-21% of total climate adaptation finance flows in 2018[7] (Swann et al. 2021; UNEP 2021). This report has shown that NbI can contribute to the protection of all infrastructure sectors from climate hazards and provide wider positive outcomes for resilience and adaptation. Decision-makers should therefore routinely consider NbI within adaptation investments decisions, as part of standard practice, and scale investments in NbI where appropriate.

The ability of NbI to generate multiple benefits simultaneously, including for infrastructure, adaptation, mitigation, and biodiversity, can increase the financial efficiency of investments and enable practitioners to draw upon finance from multiple different sources (WWAP 2018). For example, it is estimated that US $1 trillion of investment in nature is required to meet the 1.5°C temperature target of the Paris Agreement between 2022-2050 (UNEP 2022b) – by using funding for infrastructure to invest in NbI, infrastructure practitioners can meet infrastructure service needs and at the same time contribute to meeting investment needs for nature-based mitigation.

All of the potential benefits of NbI should be factored into assessments of different infrastructure options. In many situations, the potential for NbI to provide multiple benefits, in addition to meeting infrastructure service needs, will swing investment decisions in their favour (WWAP 2018).

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4. Current investment trends are forecast to culminate in US $79 trillion of investment over the period 2016-2040, leaving a US $15 trillion investment gap to meet the US $94 trillion.
5. Global infrastructure spending has remained broadly constant at around 3% of GDP over the last decade. To meet the investment needs, this would need to increase to 3.5%.
6. Finance flows to NbS are currently US $154 billion per year. This is less than half of the US $384 billion per year in NbS needed by 2025, and only a third of that needed by 2030 (US $484 billion per year) (UNEP 2022b).
7. Funding was driven by a few major bilateral donors, including Germany, the UK, Japan, and Sweden. The European Union, Asian Development Bank, Green Climate Fund, and International Fund for Agricultural Development were among the largest multilateral donors (Swann et al. 2021).

Barriers

The deployment of NbI has the potential to provide many benefits in principle. However, NbI solutions are complex, and there are multiple uncertainties, challenges and constraints that mean that the deployment of NbI is not yet being planned, financed, and implemented consistently as part of mainstream practice on sustainable infrastructure. This section outlines the key challenges to scaling NbI.

Limits to performance

It is clear that NbI has many benefits to offer for meeting global challenges. However, there can be limits to their capacity for service provision. For example, there is evidence to suggest that the protective services of NbI are most effective for mitigating hazards of low intensity, and less so for climate hazards of higher magnitude (Kapos et al. 2019). Forests are considered most effective at mitigating small floods and can contribute up to 10-20% reduction in flooding for floods up to one-in-100-year magnitude (Buechel et al. 2022; Dadson et al. 2017), and potentially up to 30% in some cases (Moos et al. 2018). Coastal NbI are considered most effective to protect coastlines against waves up to 0.5m high (Narayan et al. 2016). Wetlands can store water and contribute to flood reduction until they reach saturation points (Acreman and Holden 2013). Similarly, although many ecosystems provide valuable carbon sinks, some may reach saturation points, above which they can no longer sequester carbon (e.g. Hubau et al. 2020). The performance limits of NbI are not fully understood, but may affect their suitability for meeting local needs, and so must be considered in the decision-making process. Further research will be needed to understand potential limits to performance in different contexts.

Variations in functional performance

The extent to which NbI can function and provide services in different contexts is uncertain, and therefore their applicability from one context to another is unclear. The capacity of NbI to provide services is impacted by multiple different factors, including ecosystem type, species type, condition and intactness, the landscape before deployment, management, the adaptive nature of NbI, and both local and wider-scale environmental and social dynamics (Browder et al. 2019). Given that these factors will change over time and location, it is likely that their functional performance will similarly vary contextually, and a given NbI will not be applicable in all circumstances. For example, studies have shown that floodplain wetlands are more likely to contribute to flood reduction than upland or headwater wetlands (Acreman and Holden 2013; Bullock and Acreman 2003). Equally, wetlands in areas of lower rainfall may be more effective at flood mitigation than those in areas of high rainfall, which are already saturated and no longer have capacity to store water (Dadson et al. 2017). Cloud forests can support drought mitigation through their ability to capture fog, whereas in other cases forests can lead to lower water availability (Browder et al. 2019). Some ecosystems are considered carbon sinks, while others can become carbon sources (World Bank 2021). The benefits of forests for sediment reduction to hydropower is not always uniformly distributed across catchments (Vogl et al. 2016). The performance of phytocaps in the solid waste sector is dependent on local climate, water storage capacity, and the influence of vegetation on the hydrological cycle, particularly in wet periods (Lamb et al. 2014). These variations in performance create additional layers of complexity for infrastructure decision-makers but must be considered in the planning and design of NbI.

Time delays to benefit provision

NbI solutions have different timeframes over which they develop, function, and have capacity for service provision (World Bank 2017; Cohen-Schacham 2019). Many NbI options take longer timescales to achieve their full potential for providing services to infrastructure compared to built infrastructure assets. For example, coral reefs can take up to five years to grow and reproduce, and longer to provide the benefit of shoreline stabilization (Browder et al. 2019) and living snow fences can take five to seven years or more to develop (United States Department of Agriculture [USDA] 2011). It can take even longer in the case of badly degraded ecosystems (Kapos et al. 2019) - degraded tropical forests can take more than 40 years to recover their capacity to function and provide services (Browder 2019; Seddon 2021; Seddon 2020). For other ecosystems, their functionality and capacity to provide services may vary seasonally, whereby their provision of services is higher in growing seasons and lower during winter and dry seasons when plants are dormant (Browder et al. 2019). For NbI that require legislation, such as the assignment of national park status, this has been known to take up to a decade to achieve in some cases. Some NbI can only be implemented at certain times of year – for example, to survive planting, trees often need to be planted at the beginning of the rainy season (World Bank 2021). The time delays to NbI development and benefit provision mean that the benefit-cost ratios that inform decision-making can change over time (Kapos et al. 2021). This can be a challenge to making decisions on infrastructure investments, as delays to achieving benefits can impact their suitability to address the infrastructure service need (World Bank 2017; Cohen-Schacham 2019). However, not all infrastructure projects will need NbI to reach 100% of their potential for service provision immediately in order to meet the need (Browder et al. 2019). Many NbI options may also provide the required service in short time frames, such as improved ecosystem management regimes, or can be combined with built infrastructure options while they develop.

Resilience of NbI

The ability of NbI to persist, function and provide services is likely to be impacted by local socio-political and environmental conditions, including climate change, however the risks to NbI are not well understood. Climate change impacts may result in the degradation of ecosystems or shifting of their location (Kapos et al. 2019). In some cases, climate change may cause the loss of existing ecosystems, and so some options that are available today may not be present to provide services to infrastructure in the future. Other risks include invasive species, pests, disease, and development, including agricultural encroachment and intensification, as well as infrastructure development. For example, it is estimated that 90% of global deforestation is due to agricultural expansion (UN 2022), which can pose risks to forest-based NbI. Equally, some NbI do not have 100% survival rates following their implementation – saltmarshes have a survival rate of 64.8%, coral reefs of 64.5% and seagrass 38% (Browder et al. 2019), based on small-scale restoration efforts (<1ha). While mangroves can contribute to wind speed reduction, extreme wind speeds associated with cyclones can lead to their destruction. It is necessary to understand the full range of potential risks in decisions on NbI, to select the most appropriate option for the given context, and to ensure their management and maintenance long-term to maximize the chance of success.

Data and information availability

Decision-making on NbI should be informed by data on different NbI options including costs, benefits, and potential effectiveness at service provision. However, data and information gaps impede the full integration of NbI into designs and can deter potential investors, leading to additional barriers to securing the funding necessary for NbI (Thorn et al. 2021). Key gaps include:

- **Information on the applicability of different NbI options to each infrastructure sector:** the majority of guidance on NbI exists for the water sector. There is limited guidance available for other sectors, such as energy, transport, or education, to support decision-makers to understand and identify the NbI that are likely to be most applicable to provide services relevant to their sector.

- **Implementation cost breakdown:** the full breakdown of implementation costs into constituent costs is typically not well documented. These should include the cost of labour, materials (e.g., seedlings, fencing), site preparation (e.g. draining, cleaning, weeding, invasive species removal), legal fees, land purchase and use (e.g. payments to landowners, permits), transportation, and machinery. Land purchases costs are likely to vary significantly, and may be higher in urban areas, which can impact the total implementation costs of different NbI options in different locations (UNEP 2014; World Bank 2021).

- **Maintenance costs:** the evidence base on maintenance costs is severely lacking and potentially overlooked in infrastructure decisions. The lack of data means that it is unclear as to whether these costs are comparable or lower than built infrastructure options in the long-term – in one study of constructed wetlands, construction and maintenance costs were found to be similar, if not slightly higher for water treatment (Liquete et al. 2016). In Nigeria, a sand nourishment project for coastal flood and erosion protection required sand replenishment every two to three years, which was too costly to maintain and therefore failed due to lack of maintenance (Browder et al. 2019). More data on maintenance is necessary to enable informed decision-making on NbI and to ensure that the financial resources for maintenance are budgeted for to maximize the potential for long-term success of NbI. This should include costs for activities such as weeding, the clearing of litter, maintenance of protective fencing, pruning or thinning, invasive species removal, tree or forest litter management, regular watering, beach nourishment, and any other additional costs such as labour, transport, and materials (World Bank 2021). Documentation of the frequency at which maintenance is carried out will be necessary to understand and compare the full costs over the lifecycle of different NbI solutions.

- **Outcomes:** data on the long-term effectiveness of NbI is lacking and poses a key barrier to informing robust infrastructure decisions. The organisations with responsibility for the monitoring and tracking of benefits, including effectiveness at service provision, rarely report the full spectrum of outcomes that result from an NbI solution. This is typically for a range of reasons, including lack of technical capacity, human capacity, funding for monitoring, and reporting requirements from funders. The benefits of NbI are typically reported in terms of number of hectares under improved management/restored, or number of trees planted, while the outcomes of NbI in terms of improved service delivery (e.g., reduction in soil erosion per unit area, water storage capacity per unit area, change in flood depth) are not routinely monitored. Where outcomes are monitored, it is seldom beyond five years, and usually in accordance with the timescale of funding provided for initial implementation of a solution.

- **Multiple additional benefits:** the potential for NbI to provide wider benefits for the environment, the economy and for societies should be a key driver of the uptake of NbI. However, these benefits are not consistently documented, and therefore unable to be compared consistently against other built and NbI options in decisions on infrastructure.

- **Gender-disaggregated data:** Men and women have different service needs, and to ensure that NbI is meeting the needs of women as well as men, gender disaggregated data should be collected and used where possible.

Management and maintenance

Whether or not NbI solutions are managed and maintained effectively can impact the effectiveness of the solution. Management and maintenance requirements over the lifecycle of some NbI can be quite large (World Bank 2021; Browder et al. 2019; Enzi et al. 2017). For example, for up to five years after establishment, tree seedlings may require regular watering, pruning, and to be protected from weeds competing for light, moisture, and nutrients (World Bank 2021). Young trees (<15 years) may need protection from both wild and domestic grazing animals, pests and poachers (Browder et al. 2019). Similarly, mangrove seedlings require protection from waves and strong currents, which may be done through the use of temporary protection such as permeable dams (World Bank 2021), and constructed wetlands need to be monitored at least four times per year, and may require the removal of invasive species, litter and sediment during the first three years.

Good long-term management and maintenance of NbI will be essential to ensuring long-term success, but can be challenging under social, economic, and political contexts that change over time (for example, in accordance with electoral cycles), where land rights are unclear, and where funding is limited (Seddon et al. 2020; Thorn et al. 2021). Long-term funding for management and maintenance of NbI is often lacking or extends for durations that are much too short (<five years), limiting the chance of success.

Human, technical, and institutional capacity

Availability of human, technical and institutional capacity can be an obstacle to scaling NbI. For example, technical skills are required to assess the most appropriate NbI solution for meeting local needs, and to monitor their outcomes over the lifecycle. Human and technical resources are necessary to manage an NbI solution and to monitor it over the lifecycle. Institutional capacity is necessary to enforce regulations on NbI and ensure that NbI is embedded within decision-making processes. Building sufficient capacity can be a challenge in some countries, and particularly small island developing states, where it can be difficult to build a critical mass (Jain et al. 2020).

Trade-offs

There are many potential trade-offs of NbI that need to be considered within the decision-making process to reduce the risk of negative outcomes. Trade-offs arise in situations where increasing the benefit for one goal, such as to meet infrastructure service requirements, can result in negative outcomes for another goal, such as for meeting other development or climate change needs (Choi et al. 2021; Ommer et al. 2022), and are particularly prevalent in cases that lack coordinated efforts to support the achievements of different goals under a common vision. For example, while some NbI, such as improved land management, do not require large amounts of land, many NbI can take up more space than built infrastructure options, and reduce land availability for other uses, such as for food production (IPCC 2019). This was demonstrated in the case of Union Carbide Corporation, a subsidiary of the Dow Chemical Company, which found that constructed wetlands for wastewater treatment would require 110 acres as opposed to four to five acres for built wastewater treatment infrastructure, but would cost much less than built infrastructure, totalling US $1.2-1.4 million compared to US $40 million for built infrastructure, be available in half the time (operational within 18 months) and have benefits including the provision of habitat for deer, bobcats and birds (The Nature Conservancy [TNC] 2013).

Many other trade-offs may arise. For example, the implementation of forest-based NbI can reduce erosion and sedimentation of hydropower reservoirs but may lead to reductions in total annual water yield in some cases (Vogl et al. 2016). The creation of urban street trees can improve road safety and provide benefits such as carbon sequestration, but may increase the presence of allergens such as pollen, which can have negative impacts on health (Raymond et al. 2017; Choi et al. 2019). The restoration of wetlands can contribute to flood mitigation but may increase the risk of mosquitos or disease through the presence of standing water (Ommer et al. 2022; UNEP 2014). NbI that requires frequent irrigation may exacerbate water scarcity (Choi et al. 2021; Chausson et al. 2020). Protecting coral reefs through the use of legislation, such as through the creation of no-fishing zones, can impact the livelihoods of local fishermen (UNEP 2014). Mechanized machinery may be required for some NbI, such as beach nourishment or dune restoration (World Bank 2021), which will have associated carbon emissions. Implementation of agricultural interventions involving livestock can reduce the need for mechanized maintenance around transmission infrastructure but may lead to increased emissions of other GHG, such as methane.

The interconnectedness of nature means an NbI implemented in one area can have trade-offs elsewhere. For example, NbI may contribute to flood mitigation in downstream locations but exacerbate flooding elsewhere. This has been documented in the UK, where flooding of farmers' fields during heavy rain can reduce flood risk to built infrastructure downstream – this trade-off is managed in some cases through payments to farmers who allow their fields to be sacrificed during periods of high rainfall. NbI can impact surface, sub-surface and atmospheric processes, including water tables and water flows, which can extend beyond the boundary of the solution, however these are not always well understood. The trade-offs of NbI will therefore vary contextually, and over space and time, which can add to the complexity of infrastructure decision-making.

Stakeholder alignment and collaboration

The deployment of NbI across the project lifecycle is complex, and will involve a diverse range of stakeholders, often more so than for built infrastructure approaches (WWAP 2018), many of whom may have different and potentially competing interests. These include local women and men, indigenous communities, infrastructure practitioners, landowners, private sector stakeholders, utility companies, different ministries within governments, agricultural sector stakeholders and stakeholders working in the nature and biodiversity space Misaligned mandates across these stakeholders pose a risk to the long-term success of NbI. Balancing the objectives of stakeholders with responsibility for the management of NbI options with those who have other objectives associated with the land can be a necessary but challenging part of scaling NbI.

Costs and who pays

Although NbI may be more cost-effective in the long-term, many will incur costs associated with implementation (e.g., land purchase, land permits, site preparation, materials such as seedlings, legal fees, labour, transport, and machinery), monitoring (e.g., equipment, labour, transport) and management and maintenance long-term (e.g., labour for weeding or litter clearing, transport, fencing to protect new saplings). Given that NbI can address multiple challenges simultaneously and therefore has the potential to provide benefits to multiple stakeholders long-term (e.g., governments, infrastructure practitioners, biodiversity stakeholders, agricultural sector, tourist industry), there are questions as to who should pay for the costs associated with NbI. This challenge is magnified by the fact that many NbI are large scale, extending to the scale of whole catchments in the case of water related NbI options, and are likely to traverse the land of multiple different landowners.

Transboundary decision-making

A further aspect to decision-making on NbI is that both built infrastructure and NbI networks can extend across country borders. Considering NbI within the context of transboundary infrastructure decisions will add another layer of complexity through the addition of more stakeholders who may have different interests. For example, the Zambezi River provides fresh water and electricity to countries including Angola, Botswana, the United Republic of Tanzania, Namibia, Zambia, Zimbabwe, Malawi, and Mozambique. Implementation of NbI options in cases such as this, whereby NbI can provide services and benefits (e.g., delivery of freshwater) to multiple countries simultaneously, is likely to involve costs and benefits that are distributed across borders. This will require coordination and cooperation of stakeholders on potentially regional scales, to implement, monitor and maintain the NbI long-term.

In the following section, this report provides key recommendations that can help to overcome these challenges and mainstream NbI in the planning, design, funding, and implementation of infrastructure.

Recommendations

Maximizing the potential of NbI to help us address our global sustainable development challenges requires actions of a broad range of stakeholders across the infrastructure lifecycle, from visioning and strategic planning through to project prioritization and preparation, financing, design, construction, operations, and decommissioning.

What can policymakers do?

- **Establish cross-sectoral and interministerial processes to break down siloes within government ministries and facilitate coordination.** Breaking down barriers between ministries such as the Forestry Department and Ministry of Agriculture, and infrastructure line ministries will be necessary to develop aligned strategies for NbI, minimize tradeoffs, increase adoption, and help to ensure their success over the long-term.

- **Strengthen the inclusion of NbI in NDCs and NAPs.** This should include quantitative targets where possible, for example the number of hectares of native forest to be restored. Concrete NbI commitments in national climate plans provide a basis for greater synergy among different policy agendas, and for effective implementation and monitoring.

- **Ensure that NbI solutions are systematically incorporated into infrastructure planning and development.** Infrastructure should be designed to maximize the use of nature, including the design of infrastructure networks which enhance the protection and management of existing natural assets, restoration of degraded ecosystems which have been impacted from previous infrastructure development, and the restoration of nature once infrastructure projects are decommissioned.

- **Public budgets should prioritize investments in NbI, including hybrid solutions, over built solutions where feasible to do so.** Ensuring that public budgets include investment in NbI can contribute to achieving national net-zero and nature-positive targets and the SDGs.

- **Mandate the collection of standardized quantitative data on costs and benefits of NbI.** Policymakers should incentivize the gathering of data, including key NbI outcomes, over the long-term in order to build a business case for NbI and to highlight the positive cost implications; this data can be used to conduct more accurate cost-benefit analyses of NbI versus built infrastructure options as part of future planning processes.

What can procurers do?

- **Mandate the incorporation of NbI into contracts for the development of infrastructure where it is feasible to do so.** For example, the design of buildings should include routine consideration of green roofs across all sectors, including on airports, ports and industrial sites, and green spaces on site. The use of nature as a means of regulating the heating and cooling needs of buildings should be considered as a matter of course.

- **Ensure new and existing methodologies for public procurement capture nature-related criteria.** Methodologies should comprehensively account for environmental, social and economic costs and benefits, and be applicable to NbI projects. They should also be forward-looking, allowing relevant criteria to be identified and incorporated at the earliest possible stage of public procurement processes.

- **Mandate the use of local labour and businesses in contracts for NbI projects.** For example, involving local micro, small and medium enterprises (MSMEs) can enhance economic benefits in local communities and empower them to protect and manage NbI.

- **Include provisions for long-term monitoring of NbI as part of operations contracts.** Monitoring of NbI should be undertaken over the long-term in order to track outcomes as the solution develops. Procurers have a role to play in incentivizing or requiring long-term monitoring, which could extend as far as 2030 (in line with the SDGs), and beyond.

What can planners and designers do?

- **Provide clients with options to embed NbI in infrastructure design where possible.** New approaches are required in which the design of infrastructure begins with nature. An assessment of existing NbI can help to identify what relevant infrastructure services are being delivered and how they can be harnessed in order to deliver infrastructure services, enhance service delivery, protect built assets, and provide benefits for stakeholders, buildings, and wider co-benefits. Decision-making on infrastructure should ensure that economic valuations capture the wide range of benefits that NbI can deliver.

- **Restore nature in the decommissioning of projects.** Where built infrastructure assets are decommissioned, nature should be restored and regenerated. Future infrastructure developed on the same site should aim to identify opportunities to optimize nature in the development.

- **Expand participation and diversity in design and implementation of NbI: co-design NbI with experts and local communities.** It is imperative that the environmental and social context is considered in the design of appropriate infrastructure solutions to maximize benefits for the three components and minimize negative trade-offs. Community buy-in will be vital to success over the long-term, and integration of local communities in the design and ongoing management and maintenance of solutions can help to ensure their successful scale-up. The design of NbI should start with the needs and challenges of the local communities, and ideally use interdisciplinarity to develop solutions to best meet the needs.

What can investors and financiers do?

- **Develop new financial and investment models** that increase private sector investment by mitigating risks and generating cash flows. accounting for various benefits, timescales, etc. For example, green bonds can bundle NbI projects with varying degrees of financial attractiveness or allocate risk depending on the type of investor.

- **Embed flexibility into funding.** Funding should be flexible to meet the needs of the given NbI project. This should include the provision of funding and associated reporting requirements over longer timeframes to account for the time that NbI take to develop. In some cases, this may include the flexibility to fund purchases to improve community buy-in and the likelihood of project success, such as the provision of alternative energy sources to remove the need for local communities to chop down trees for firewood.

- **Ensure nature is included as an eligibility criterion for funding across all infrastructure, development, and application funds.** Funders should develop a nature-based criterion for funding applications and prioritize applications which emphasize nature. Given the intertwined relationship of water and NbI, and applicability of NbI to buildings across all sectors, adaptation funds for water-related sectors and buildings should mandate the inclusion of nature-based and hybrid solutions where feasible.

- **Provide investment for the monitoring of NbI outcomes and mandate the tracking of outcomes in reporting requirements.** This is required for monitoring of outcomes over the short, medium, and long-term. Funding for monitoring the outcomes of NbI is a significant gap and will be crucial for evaluating the benefits and costs over the short, medium, and long term, beyond the end of projects. To ensure that these are tracked long-term, funders should specify the tracking of outcomes in reporting requirements.

- **Emphasize multifunctionality requirements in investments.** Funders and financiers of NbI can require multifunctionality to be incorporated into the design and implementation of solutions, in order to scale the implementation of NbI which can deliver multiple benefits, for climate adaptation, mitigation and the SDGs.

What can researchers do?

- **Create taxonomies of NbI solutions applicable to each infrastructure sector.** The research and development of a framework of applicable NbI solutions will guide uptake under the different NbI functions which have been identified. This should include identification of which NbI solutions can protect infrastructure sectors from different climate impacts.

- **Research the functioning and capacity of NbI to provide benefits and potential trade-offs in different contexts.** Further research is needed on the biophysical properties and limits of NbI to understand their functioning in different contexts and their likelihood to persist and provide benefits. This should include research into the impact of NbI on hydrological flows, soil stabilization, and other physiological properties. Recognizing where NbI will not provide benefits will be important to help understand the potential limits and trade-offs of NbI.

- **Research the potential scale of benefits of NbI and their limits.** More quantitative information is required on the extent to which NbI can deliver benefits, under different scenarios (including future population, development, and climate), and the limits to their potential to deliver benefits to the SDGs and Paris Agreement.

- **Research funding options for NbI, including the potential of different NbI to deliver returns on investment (ROI).** Funding of NbI is needed to help bridge the current investment gaps within both the nature and infrastructure space. Through identification of returns on investment, researchers can help to overcome some of the barriers to investment in order to support the scale-up of NbI.

- **Develop new methodologies for decision-making** that enable systematic assessment of NbI and hybrid options alongside traditional built infrastructure solutions at scale.

- **Develop and refine models and assessment tools that can support decision-making on NbI.** Models that enable assessment of the impact of NbI and hybrid options on infrastructure services (including water flows, water quality, storm protection) and tools for cost-benefit analysis which capture the various costs and benefits that NbI can provide over time can help to inform decision-making. This should include the development of new visual models and datasets that enable the tracking of NbI condition and health over time.

- **Continue to build an evidence-base: undertake monitoring and develop case studies of NbI outcomes in different contexts.** NbI tend to be highly context specific. Case studies and long-term monitoring and evaluation will help to build an evidence base and enhance the case

Box 3: Resources on NbI:

- Engineering With Nature atlas: https://ewn.erdc.dren.mil/
- European Union Natural Water Retention Measures (NWRM) platform: http://nwrm.eu/
- IISD's Global Resource Center for Nature-based infrastructure: https://www.iisd.org/projects/nature-based-infrastructure-climate
- The Natural Capital Protocol: https://capitalscoalition.org/capitals-approach/natural-capital-protocol/?fwp_filter_tabs=guide_supplement
- Nature-based Solutions Initiative: https://www.naturebasedsolutionsinitiative.org/
- ThinkNature Platform: https://www.think-nature.eu/

for investment and scale-up of NbI in different contexts. The gathering of data on outcomes will be crucial for informing decisions on NbI.

- **Develop frameworks for capturing relevant data on NbI.** The standardization of relevant NbI data which can be used in decisions on infrastructure and compared with built infrastructure solutions will help to inform monitoring and evaluation programmes and enable systematic evidence gathering across sectors, geographies, and other contexts. Researchers will have a key role in identifying which datasets and metrics should be focused upon in the case of NbI.

What can the international community do?

- **Develop standardized data and indicators on NbI to guide systematic monitoring and comparison of costs and benefits in infrastructure and investment decisions.** The standardization of quantitative metrics and data types for making informed decisions on NbI will be essential for guiding the development of monitoring strategies and benchmarks for success and to ensure that data is comparable across different NbI interventions, sectors, and contexts. These should be comparable with built infrastructure metrics and should help to facilitate scale-up of NbI across sectors. Where qualitative metrics are identified, these should be standardized to enable evaluation through multicriteria analysis.
- **Develop sector-specific good practice guidelines and design standards to guide the systematic embedding of nature in infrastructure development based on their ability to provide infrastructure services.** Guidelines for scaling NbI within each infrastructure sector will enable systematic consideration of different NbI options and their uptake within the sector.
- **Support training and capacity building in NbI among all relevant stakeholders.** There is a need for technical skills and expertise across countries and in sectors including infrastructure and nature. Funding and technical support to enable skills development will be key to ensuring sufficient capacity to implement and scale NbI solutions across countries.
- **Build momentum on NbI, and increase ambition, including through an annual global conference on NbI.** This will be important to enhance partnerships and share vision, best practices, case studies and knowledge on developing NbI projects that deliver balanced benefits for adaptation, mitigation, and development. This will help align national governments and practitioners in approaches and aid in keeping nature at the center of national strategies.

Concluding remarks

Countries across the world are experiencing the major challenges of meeting development needs, adapting to climate change, and halting global temperature rise and biodiversity loss. Built infrastructure systems are limited in their potential to provide synergized progress on global agendas, and in many cases increase GHG emissions and cause the loss, fragmentation, and degradation of natural ecosystems. In contrast, NbI can provide many infrastructure-relevant services and lead to mutual progress on global agendas in a balanced way, and often more cost-effectively, if implemented strategically.

This report has provided a framework for thinking about how NbI can be integrated into infrastructure systems with respect to the provision of infrastructure-relevant services and wider benefits. NbI can substitute for built infrastructure assets to deliver infrastructure services directly, complement built assets to enhance the functioning of infrastructure systems and the quality and reliability of their services, protect infrastructure assets and the resources that they depend upon from climate impacts, and increase the resilience of the workforces that underpin the functioning of infrastructure systems. NbI can also provide multiple additional benefits, beyond the primary intended service, including carbon sequestration, diversified income streams for local communities and habitat for biodiversity, which are critical to advancing progress on global challenges.

The development of NbI is occurring, however this has not yet been achieved at scale or as part of standard practice. This report has shown that there is significant potential to scale NbI within infrastructure. NbI can be integrated into infrastructure systems across all 13 infrastructure sectors analysed. Three sectors - culture and recreation, health, and water - have an opportunity to implement NbI for the delivery of the sector's service. Ten sectors can implement NbI to improve the quality and reliability of the sector's service. All sectors can use NbI to protect their built assets from climate impacts and safeguard service provision. All can deploy NbI to improve the well-being and resilience of workforces, and all can implement NbI to provide multiple additional benefits to societies, economies, and biodiversity.

Through the scaling of NbI within infrastructure, countries have significant opportunities to advance progress on national policy commitments under international agendas including the 2030 Agenda on Sustainable Development, the Paris Agreement, and the Convention on Biological Diversity. When considered across a subset of eight infrastructure sectors, this report has shown that when NbI is combined with built infrastructure, infrastructure systems can have greater impact on the SDGs than via built infrastructure alone, influencing 95% of SDG targets across all 17 SDG goals. When assessed on an individual sector basis, the integration of NbI can influence a much broader range of SDG targets for every sector compared to built infrastructure assets on their own. The broader influence on the SDG targets is owing to the multiple additional benefits that NbI can provide for biodiversity, societies and the environment, and points to the importance of recognizing the wider value of NbI for sustainable development outcomes in infrastructure decisions. This report found that NbI can also help to safeguard existing progress on the SDGs across all sectors from climate impacts, through protecting infrastructure systems and the resources that they rely upon from climate hazards, while simultaneously providing services that can increase the resilience of wider societies, economies and the environment to climate change. There is scope for NbI to provide broader benefits to climate mitigation, beyond carbon sequestration and avoided land use change. Through strategic planning of NbI across infrastructure systems, NbI can help to reduce emissions embedded across the lifecycle of built infrastructure assets, by avoiding or reducing the need for built infrastructure, lowering requirements for built infrastructure maintenance, and reducing the frequency at which built infrastructure assets require repair and replacement. At the same time, implementation of NbI can help to influence three of the four goals under the new Kunming-Montreal Global Biodiversity Framework of the Convention of Biological Diversity, including 65% of its targets.


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By scaling up NbI, infrastructure can be a key route through which countries can meet their national development needs, reverse the global loss of natural ecosystems, help to protect remaining carbon sinks, create additional opportunities for emissions reduction, and increase the resilience of economies, societies and biodiversity. The potential for NbI to provide multiple benefits simultaneously offers significant potential to help close the infrastructure and nature financing gaps whilst generating economic benefits for infrastructure, societies, and economies. This can help to relieve the financial burden of infrastructure development on developing economies, which have the largest infrastructure investment gaps, and which are home to natural ecosystems that are internationally recognized for services including carbon sequestration.

The large amount of investment forecast for infrastructure provides a huge opportunity to embed consideration and prioritization of NbI in infrastructure planning, decision-making and investment. This report envisions:

1. Mainstreamed consideration of NbI within infrastructure plans, decisions, and investments, as part of standard practice;
2. Decision-makers to use some of the investments they have earmarked for infrastructure to invest in NbI;
3. Strategic planning of NbI within national commitments under global agendas (e.g., National Infrastructure Plans, National Adaptation Plans, Nationally Determined Contributions and National Development Plans).

To achieve this vision is complicated. There are various complexities and uncertainties associated with the functioning of NbI in different contexts, limits to service provision, temporal delays to benefit accrual and potential negative trade-offs. Much more work will be required to realize the benefits of NbI in reality, including new research on NbI, the creation of sector-specific guidance, and the development of new policies and regulations to ensure that the benefits of NbI are distributed equitably, particularly amongst more vulnerable groups, such as women and girls and indigenous communities. Funding of NbI across the lifecycle is essential to the wider uptake of NbI, and should account for the full spectrum of costs and the longer timeframes of NbI compared to built infrastructure. The long-term monitoring and management of NbI will be critical to minimize potential negative trade-offs, and to maximize the benefits that NbI can provide for sustainable development, climate change and biodiversity.

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