Sustainable Asset Valuation Tool

NATURAL INFRASTRUCTURE

IISD International Institute for Sustainable Development

MAVA FONDATION POUR LA NATURE

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Sustainable Asset Valuation Tool: Natural Infrastructure

March 2019

Written by Andrea Bassi, Georg Pallaske, Laurin Wuennenberg, Lidia Graces and Lydia Silber

This document is not meant to be an original contribution. Instead, it is a review that summarizes available knowledge in the literature for a given infrastructure type, including, for instance, the policy landscape and data availability. As a result, this document (both the light screening and in-depth review) were utilized to inform the creation of the SAVi model, a simulation tool that integrates knowledge from various disciplines and sectors for sustainable asset valuation.

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Abbreviations and Acronyms

CRP	Conservation Reserve Program
EU	European Union
FWS	free water surface
GHG	greenhouse gas
GI	green infrastructure
IUCN	International Union for Conservation of Nature
LEED	Leadership in Energy and Environmental Design
NBD	nature-based defence
NCFF	Natural Capital Financing Facility
NGO	non-governmental organization
NI	natural infrastructure
NNBI	natural or nature-based infrastructure
O&M	operations and maintenance
PPP	public–private partnership
SAVi	Sustainable Asset Valuation tool
SDG	Sustainable Development Goals
SRC	stormwater retention credit
SSF	Sub Surface Flow
TEEB	The Economics of Ecosystems and Biodiversity
TSS	total suspended solid
UHI	urban heat island
UNEP	United Nations Environment Programme
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

PART I: LIGHT SCREENING

Definition of sustainable infrastructure	IISD defines ***natural infrastructure* (NI)** as ecosystems that provide infrastructure through services that are inherent to such ecosystems, while also perpetuating active conservation efforts and the enhancement of the environments they are embedded in. We find that "natural infrastructure," "nature-based infrastructure" and "green infrastructure" are interchangeable terms in literature. For the purposes of this report, and the development of a specific module of the Sustainable Asset Valuation (SAVi) tool, IISD chose to use the term "natural infrastructure." There are two main types of NI that are covered in this report and included in SAVi: (1) "natural," as defined above (e.g., wetlands); (2) "green-grey," urbanized NI; it tends to hybridize NI and grey infrastructure into easily implementable structures to urban environments (e.g., permeable pavements, green spaces).

Main types discussed as NI	To better characterize the various types of "natural" and "green-grey" infrastructure, we provide examples starting from the ecosystem service that NIs provides, as follows:.
	To better characterize the various types of "natural" and "green-grey" infrastructure, we provide examples starting from the ecosystem service that NIs provides, as follows:
	• *Reduced, controlled flooding*
	  ◦ **Natural**: wetland (constructed, restored), mangroves, reed beds, marshes, dunes
	  ◦ **Green-grey**: permeable pavements, bioswales, green roofs, urban gardens
	  ◦ *Example: "Investment in wetland conservation [in the Smith Creek basin of southeastern Saskatchewan, Canada] provides a positive social return on investment: every CAD 1 invested in retention yields CAD 7.70 in flood control, nutrient removal, recreation, flood control and carbon sequestration; and every CAD 1 invested in 25% restoration of lost wetlands yields CAD 3.22 over a 10-year time frame" (Pattison-Williams, Pomeroyb, Badiouc, & Gabor, 2018).*
	• *Climate Regulation*
	  ◦ **Natural**: wetlands (constructed, restored), reed beds, mangroves, reefs, marshes, forests, peatlands
	  ◦ **Green-grey**: green roofs, green spaces, urban gardens
	  ◦ *Example: Houston's 663 million trees are providing cooling that reduces the need for air conditioning valued at USD 131 million annually, while San Francisco's urban forest canopy saves an estimated USD 27 million in natural gas costs and USD 305 million in electricity (Roth, 2013).*
	• *Carbon Dioxide Sequestration*
	  ◦ **Natural**: wetlands (constructed, restored), forests, peatlands
	  ◦ **Green-grey**: green roofs, urban gardens
	  ◦ *Example: Between tree planting and the implementation of permeable pavements and green roofs, Philadelphia saved approximately USD 1.94 billion to USD 4.45 billion by using natural and green-grey infrastructure in order to manage city stormwater. The city's Green City, Clean Waters initiative saves 370 million kilowatt hours, 700 million BTUs and approximately USD 34 million, while cutting carbon dioxide emissions by 1.1 million tonnes over a 40-year period (Roth, 2013).*
	• *Biodiversity*
	  ◦ **Natural**: wetlands (constructed, restored), mangroves, reefs, marshes, forests
	  ◦ **Green-grey**: urban gardens, green overpasses for animals
	  ◦ *Example: In Cambodia, the Ream National Park provides fish breeding grounds and other subsistence goods from mangroves worth an estimated USD 600,000 per year and an additional USD 300,000 in services such as storm protection and erosion control (Emerton, Seilava & Pearith, 2002).*
	• *Water: Quality, Access and Potability*
	  ◦ **Natural**: wetlands (constructed, restored), reed beds
	  ◦ **Green-grey**: green roofs, green spaces-bioretention, swales, infiltration
	  ◦ *Example: The number of total suspended solids (TSSs) in the Union Carbide Corporation's retention pond exceeded allowable limits, making for constant algal bloom threats. After implementing a constructed wetland, it took only 18 months for all TSS requirements to be met and saved the company USD 38.5 million in sequencing batch reactor construction. The sequencing batch reactor would have taken 48 months to construct (DiMuro et al., 2014).*
	• *Reduction of Erosion*
	  ◦ **Natural**: healthy reefs, preservation of dunes, beach grasses, mangroves, coastal marshes
	  ◦ **Green-grey**: beach nourishment (Cunniff & Schwartz, 2015)
	  ◦ *Example: "Mangroves protect the erosion of coastlines, thus preventing the loss of valuable agricultural land and property. Ruitenbeek (1991) estimates the benefit of erosion control at INR 1.9 million per household per year for Bintuni Bay, Indonesia" (Bann, 1998).*
	• *Energy Provisioning*
	  ◦ **Natural**: currents and movement of water in a directed way
	  ◦ **Green-grey**: windmills, hydroelectric, solar panels, photovoltaics, geothermal
	  ◦ *Example: The equivalent of 20,000 to 64,000 households' electricity could be saved by eliminating the need to pump water from miles away to Los Angeles (Roth, 2013).*

Indicators used to measure performance	NI is generally measured through an assessment of the ecosystem services provided. The most prominent studies in this area are the Millennium Ecosystem Assessment and The Economics of Ecosystems and Biodiversity (TEEB). The main indicators used are biophysical and monetary. The former measures the ecosystem service provided; the latter assigns an economic value to the ecosystem service. **Specific Tools:** Millennium Ecosystem Assessment • Analyzes a broad range of indicators, from vulnerability of people and biodiversity to air quality; identifies the relevance of NI and classifies ecosystem services. TEEB • Provides information on how to economically value ecosystem services; Chapter 5 of TEEB's Ecological and Economic Foundations uses the Common International Classification of Ecosystem Services of the European Union (EU) (Kumar, 2010); TEEB (2013) has compiled a list of ecosystem services provided by NI and related indicators. **Selected indicators:** • Produced/harvested crops, fruit, wild berries, livestock, fish, etc. The unit of measure used is tonnes and/or hectares. For fish production, the unit of measure used is live weight caught in tonnes. • Raw materials used, such as sustainably produced wool, skins, leather, plant fibres, timber, etc. in million cubic metres. • Provision of water supply, in million cubic metres. Other indicators for water availability include: water scarcity (proportion of total water resources used); water use intensity by economic activity; human and economic losses due to water-related natural disasters; percentage of population living in water-hazard-prone areas; land affected by desertification; water footprint; climate moisture index; soil moisture. • Water regulation (surface water, aquifers, groundwater, etc.). The indicators used include an ecosystem's infiltration capacity (volume of water through unit area/per time unit), soil water storage capacity in mm/month and floodplain water storage capacity in mm/month. • Water purification and waste management. The indicators used include the removal of nutrients by wetlands in tonnes (or percentage) and water quality in aquatic ecosystems (e.g., sediment quality, turbidity, nutrient concentration, etc.). Other indicators for clean water include: proportion of population using an improved drinking water source; proportion of population using an improved sanitation facility; proportion of cities obtaining water supplies from protected areas; area of wetland used in water treatment; access to improved drinking water based on change in water quality. • Climate regulation via carbon sequestration, in gigatonnes of carbon dioxide (total amount of carbon stored per hectare). • Moderation of extreme events such as floods and droughts. The indicator used is the probability of incident and trends in number of damaging natural disasters. • Cultural and social services include landscape and amenity values, ecotourism and recreation and cultural values seen in education, art and research. Indicators for these services include changes in the number of residents and real estate values, number of visitors to touristic sites, amount of nature tourism, the number of educational excursions to a site, number of scientific publications, TV programs, studies, books, etc. featuring the area.
Shortcomings of grey infrastructure	The shortcomings of grey infrastructure can be summarized by two main points: • First, if we consider the full life cycle of the asset, grey infrastructure proves to be less cost-effective, more so when we considered its limited efficiency in the face of increasingly extreme climatic events. • Second, grey infrastructure cannot provide the socioeconomic co-benefits provided by NI, such as aesthetic enjoyment and tourism (TEEB, 2011) and climate change mitigation through carbon storage and sequestration (United Nations Environment Programme [UNEP], 2014). Grey infrastructure often offers immediate solutions and returns. However, it may cost more than NI (the typical cost for a natural shoreline ranges between USD 0 and USD 6,562 per metre; capital costs for a seawall ranges between USD 6,500 and USD 9,800 per metre and can be as high as USD 32,800 per metre) (Cunniff & Schwartz, 2015). Furthermore, operations and maintenance (O&M) costs can be as much as six times higher for seawalls, and they bring no additional benefits beyond their intended purpose (Sutton-Grier et al., 2018). In addition, NI brings a range of positive externalities or ecosystem services. Continuing with the example of seawalls, while solving the problem locally, constructed seawalls may amplify risks and shift them elsewhere. For example, in order to mitigate flooding in the north of the Suffolk Coast, grey coastal defences were constructed. This exacerbated flooding in the south at an alarming rate, causing the cliff in southern East Lane to recede 17 metres in 12 months (Environment Agency, 2015).

<table>
<tr><td>Advantages of NI investments</td><td>
NI is economically advantageous in comparison to grey infrastructure. NI tends to already be in place, and by investing in it we are enhancing its capacity. The flexibility, adaptability and reversibility of NI makes it a low-regret and low-cost solution, whereas the high costs associated with grey infrastructure tend to make it more irreversible.

A major factor contributing to the higher cost-effectiveness of NI is its diversity of functions and associated co-benefits. The specific advantages of NI are summarized as follows:
1. Land security: Protection against erosion, flood management, drought mitigation and biodiversity preservation are all benefits provided by NI.
2. Climate regulation: Carbon storage/sequestration and global cooling mechanisms are unique qualities of NI.
3. Water security: Water quality and potability regulation, water retention and supply regulation, water flow regulation (riverine flood control, urban flooding, coastal flooding).

Natural and nature-based infrastructure can also enhance and protect the grey structure in place. An example is green infrastructure for urban water management. Grey infrastructure often contributes to a specific issue in urban areas but does not necessarily support the mitigation of stormwater-related externalities, such as peak flow (U.S. Environmental Protection Agency [EPA], 2014).
</td></tr>
<tr><td>Shortcomings of natural and green-grey infrastructure</td><td>
Wetlands:
• Difficult to define exact performance outcomes due to multiplicity of services provided.
• Land requirements can hinder the implementation of NI projects; grey infrastructure often requires a fraction of the land to provide the same level of service.

Green roofs:
• Structural loading implications and constant monitoring required to ensure that vegetation and soil are healthy and properly filtering water.

Green spaces:
• NI (vegetated areas in cities) are most useful in urban flood mitigation for intercepting the first increment of rain. During larger rainfall events, soil becomes quickly saturated and most rain will flow as surface runoff (McDonald, 2015).

Water harvesting:
• In homes where the occupancy is more than two people, rainwater harvesting needs to be backed up from public supplies (Booth, Hammond, Lamond, & Proverbs, 2012).
• Project monitoring is difficult and expensive given the episodic nature of storms and because it is easy to miss the important flux of water needed for the sampling (Booth et al., 2012).

Permeable surfaces:
• Highly sensitive to large loads; constant monitoring to ensure pollutants that have infiltrated the pavement do not enter underlying soils and that water does not raise groundwater levels enough to cause basement flooding (UNEP, 2014). Project monitoring is difficult and expensive (Booth et al., 2012).
</td></tr>
<tr><td>Risks associated with natural and green-grey infrastructure</td><td>
Wetlands:
• Performance is affected by low temperatures.
• Removal of coliform may not be sufficient and supplemental disinfection may be required.
• Potential breeding ground for mosquitoes and other disease vectors.
• Bird populations can pose risk to air traffic if an airport is nearby.
• Methane production may create additional costs if this surpasses greenhouse gas (GHG) cap-and-trade agreements.
• Pre-treatment of highly toxic water may be required if the wetland is not suited to treat it.

Green roofs:
• Failure to attain Leadership in Energy and Environmental Design (LEED) credits due to having to comply with structural load implications.
• Roof damage due to roots growing through the substrate and incliners.
• Potential flooding and mould growth.

Green spaces:
• Negative downstream impacts to higher water infiltration.
• Risk of asthma and allergy.

Water harvesting:
• Impacts on water balance and downstream ecosystems.
• Potential breeding ground for mosquitoes and other disease vectors.
• Air pollution, animal or bird droppings, insects and dirt may affect rainwater quality.

Permeable surfaces:
• Areas with high contaminant and pollutant levels risk groundwater and soil contamination.
• May have clogging issues in locations using road salt.
• Structural integrity may be affected by oil spills from cars.
</td></tr>
</table>

Main roadblocks for the adoption of NI	**Costs and financing**: • Inability to quantitatively evaluate and compare project costs: Assessments and cost-benefit analyses are site-specific and therefore adoption of NI and corresponding evaluations cannot be globally applied, nor are they necessarily comparable. • High transaction costs: Natural infrastructure requires the involvement of multiple stakeholders, as negotiating with stakeholders, working across jurisdictions and coordinating with landholders to implement NI projects is expensive. • Long time horizons: NI projects take longer to reach their full capacity than grey infrastructure alternatives because the ecological processes required to capture the full potential range of ecosystem services may take up to years to develop. • Insufficient financing: It is unclear who should take on the financial burden of these types of projects and for how long. Furthermore, funding is often provided on time horizons that are not long enough for the nature of the NI project. • Small project scale: NI projects tend to be smaller than their grey infrastructure alternatives, making it difficult to attract investors who are interested in revenue generation normally associated with larger projects. • Lack of coordination between funding goals and development objectives: Project financing and implementation are often not coordinated within the country where the project is being funded, which is a big challenge in countries that depend on external funding. • Lack of revenue streams: Standalone NI projects often lack any revenue-generating potential to pay back their financing. However, NI projects can be financially viable if they complement traditional revenue-generating infrastructure projects. **Lack of knowledge, technical guidance and awareness**: • Issues of a vague and immature concept: NI is not a clearly defined concept and captures a diversity of natural functions/services that (might) have beneficial anthropogenic value. But the lack of clarity and systemic approaches make it difficult to apply a quantitative assessment. • Institutional inertia and pervasive knowledge gaps: infrastructure decision-makers do not have a clear understanding of the socioeconomic and environmental benefits of NI. • Benefit estimation issues: Utilities have struggled to quantify the ecological and economic benefits of NI, a task made more difficult by imperfect science. **Limited policy support**: • Lack of clarity on how NI complies with environmental regulations: Variability in performance and lack of consistent results are an example. • Lack of policy frameworks that enable permitting and encourage or provide financing for NI: At present, there is a need for a nationwide permitting process to allow streamlining of permitting across state and federal levels in most countries. • Lack of policies explicitly addressing NI permitting: Policies are needed to specifically support the permitting of NI alternatives over grey infrastructure. **Permitting challenge**: • Multiple permit requirement. • Complexity of permits leads to individual interpretation and implementation.
Policy interventions	The main enabling conditions for achieving scaling and investments into NI are: **1. Rating systems and regulatory mechanisms** • LEED, SITES and Parksmart serve as guides for green infrastructure; zoning codes and building codes, stormwater ordinances. **2. Market instruments** • Payment for ecosystem services (e.g., REDD+); innovative financing models (e.g., the Washington D.C. Stormwater Retention Credit Trading Program allows landowners to trade their credits so that others can meet the regulatory requirements for stormwater retention). **3. Financing** • Direct investment from national governments, development banks, organizations, communities and individuals; public–private partnerships to allocate key project risks to the private sector; tax benefits. **4. Capacity support and awareness** • Awareness-raising through the regular dispersion of results and knowledge, open communication, feedback, transparency in O&M, pilot testing; promoting interagency coordination to reduce the transaction costs involved with NI projects.

Actors involved	**Government**: Ministries for the environment and infrastructure, public utility companies (e.g., fresh water and wastewater services), international governance structures (e.g., EU). **Insurance companies**: Strategic partnerships between insurance companies and non-governmental organizations (NGOs) can be critical for advancing the business case for sustainability. **The private sector**: Large infrastructure companies (e.g., water supply), agricultural firms and commodity traders (e.g., timber), mining companies, tourism/recreation. **NGOs**: Conservation NGOs, wildlife protection, multilateral agencies (e.g., UN Environment; multilateral development banks), foundations. **Individuals**: Households affected by and/or interfering with and/or supporting NI, for example by planting urban gardens.
Existing sustainability standards	**Indicators**: • Millennium Ecosystem Assessment • TEEB **Green Infrastructure Measurement Examples**: • European Environment Agencies • Biodiversity Information System for Europe • CEEQUAL (HDRinc) • Green Roads (HDRinc) • Envision (HDRinc) ***Buildings and Structures Measurement Examples***: • Building Research Establishment Environmental Assessment Method (BREEAM) • Excellent in Design for Greater Efficiencies (EDGE) • ENERGY STAR • LEED

PART II: IN-DEPTH REVIEW

1.0 Introducing NI

1.1 Definition of NI

Until recently, there has been no universally agreed upon definition of NI in the literature. The terms "natural infrastructure" and "blue infrastructure" have been coined relatively recently, and most definitions are still very broad (da Silva & Wheeler, 2017). NI was first used in 1996 to highlight the importance of wetlands in managing freshwater supply (Sajaloli, 1996). It has been defined as "any piece of nature that provides important benefits to those in a city" and is also referred to as "ecological infrastructure" (McDonald, 2015). The first description of blue infrastructure was mentioned in the context of reducing risks in floodplains and other flood-prone areas during a project in Brazil. This project aimed at increasing coastal resilience by establishing a network of green and blue infrastructure components (Frischenbruder & Pellegrino, 2006). Natural and nature-based infrastructure (NNBI) exploits the inherent properties and ecosystem services of natural environments for specific purposes for which currently grey infrastructure solutions are often applied. These include flood protection, water quality and flow management. Table 1 provides examples of NI components that are applied to specific watershed management issues and lists the equivalent of grey infrastructure that is typically used.

The concept of NI has recently gotten more traction in the literature published by business groups and institutional bodies. An example is the European Commission (2013), which defines NI as "strategically planned networks of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (Wang & Banzhaf, 2018). NI has also been defined as strategically planned and managed land that conserves and adds to ecosystem values while also providing benefits to populations (Benedict & McMahon, 2006).

We find that "natural infrastructure," "nature-based infrastructure" and "green infrastructure" are interchangeable terms in literature. For the purposes of this paper and the development of a specific module of the Sustainable Asset Valuation (SAVi) tool, IISD chose to use, primarily, "natural infrastructure" or NI.

It is important to note that most definitions of NI include both natural and anthropogenic components, also referred to, respectively, as "green" and "green-grey." As a result, there are two main types of NI that are covered in this document, and included in SAVi:

- "Natural" is as defined above (e.g., wetlands). We refer to this as NNBI.
- "Green-grey" is urbanized NI; it tends to hybridize NI and grey infrastructure into easily implementable structures for urban environments (e.g., permeable pavements, green spaces).

IISD defines NIs as networks of land or ecosystems that provide infrastructure through services that are inherent to such geographical areas, while also perpetuating active conservation efforts and the enhancement of those environments.

Table 1 compares NI and grey infrastructure in the context of water management, with services to be provided, and indicates the types of infrastructure capable of providing such services.

Table 1. Examples of NI and GI strategies and their corresponding built infrastructure

Water management issue (Primary service to be provided)		Green Infrastructure solution	Location: Watershed	Floodplain	Urban	Coastal	Corresponding Grey Infrastructure solution (at the primary service level)
Water supply regulation (incl. drought mitigation)		Re/afforestation and forest conservation	■				Dams and groundwater pumping Water distribution systems
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Water harvesting*	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
Water quality regulation	Water purification	Re/afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (bioretention and infiltration)			■		
		Permeable pavements*			■		
	Erosion control	Re/afforestation and forest conservation	■				Reinforcement of slopes
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
	Biological control	Re/afforestation and forest conservation	■				Water treatment plant
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
	Water temperature control	Re/afforestation and forest conservation	■				Dams
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Green spaces (shading of water ways)			■		
Moderation of extreme events (floods)	Riverine flood control	Re/afforestation and forest conservation	■				Dams and levees
		Riparian buffers		■			
		Reconnecting rivers to floodplains		■			
		Wetlands restoration/conservation	■	■	■		
		Constructing wetlands	■	■	■		
		Establishing flood bypasses		■			
	Urban stormwater runoff	Green roofs			■		Urban stormwater infrastructure
		Green spaces (bioretention and infiltration)			■		
		Water harvesting*	■	■	■		
		Permeable pavements*			■		
	Coastal flood (storm) control	Protecting/restoring mangroves, coastal marshes and dunes				■	Sea walls
		Protecting/restoring reefs (coral/oyster)				■	

Source: UNEP, 2014.
** indicates built ("grey") elements that interact with NI and seek to enhance their water-related ecosystem services*
Note: UN Environment uses the term "green infrastructure" as an umbrella term that includes "natural infrastructure" in this context.

1.2 Advantages of NI Versus Conventional Investments

Grey infrastructures, especially those focused around water, are generally attractive investments due to their ability to offer immediate solutions and returns. However, in the long term, the difference between capital and maintenance costs between grey infrastructure and NNBI is significant.

There are two reasons for this: (i) over the lifetime of the project, the cost of grey infrastructure is most often higher than intervening on NI and (ii) NI brings several additional benefits relative to grey infrastructure. An example of the cost advantage is provided next, and this topic will be explored in more detail in later sections of this document. After the cost example, three main benefits of NNBI are presented: (1) land security, (2) climate regulation and (3) water security.

The cost of building, operating and maintaining a built infrastructure project is more expensive than allowing ecosystem services to carry out their natural functions. As seen in Figure 1, comparing a seawall with a natural/living shoreline shows that the maximum capital cost for NNBI is just about as high as the lower end of capital costs for grey infrastructure (Cunniff & Schwartz, 2015). Capital costs for seawalls can be as high as USD 32,800 per metre, but typical costs range between USD 6,500 and USD 9,800 per metre, whereas typical costs for a natural/living shoreline ranges between USD 0 and USD 6,562 per metre. In addition to higher capital costs, O&M costs can be as much as six times higher for seawalls, and they generate no added benefits beyond their original purpose (Sutton-Grier et al., 2018). When grey infrastructure is designed to have multiple objectives, its efficiency can often be muddled, as it may shift amplified risks elsewhere. Some variation of environmental degradation is likely to coincide with the construction of a grey project, which can lead to a decline in water quality (Oppermann, 2009; UNEP, 2014). On the other hand, NNBI benefits (such as oyster and salt marsh habitat components) capture positive externalities, including fish production and water quality.

Overall, the value of NI is increasingly being explored. Results show that NI can provide the same level of protection as its grey alternatives. However, studies conducted in Canada assessing the value of NI under different climate change scenarios show it to be more resilient and adaptable than grey infrastructure alternatives, illustrating the growing importance of NI. For example, in the Canadian Region of Peel, the replacement value of the stormwater quality and quantity services provided by wetlands, forests and meadows in the area were calculated to be approximately CAD 704 million under current conditions. This value increases to CAD 764 million under climate change conditions. Therefore, not only are NI benefits commensurate with their engineered counterparts, but they are also critical in the face of climate change (Saini, Singh, Koveshnikova, & Paudel, 2018).

Infrastructure Type[a]	Installation Cost[b]	Annual Maintenance/ Repair Cost[b]	Annual Water Quality & Fish Production Value[c]
Built (seawall/bulkhead)	\$6,500 - \$9,800 m^{-1}	\$0 - \$1,710 $m^{-1}yr^{-1}$	\$0 $m^{-2}yr^{-2}$
NNBI (natural/living shoreline)	\$0 - \$6,562 m^{-1}	\$0 - \$328 $m^{-1}yr^{-1}$	\$1 - \$7 $m^{-2}yr^{-2}$

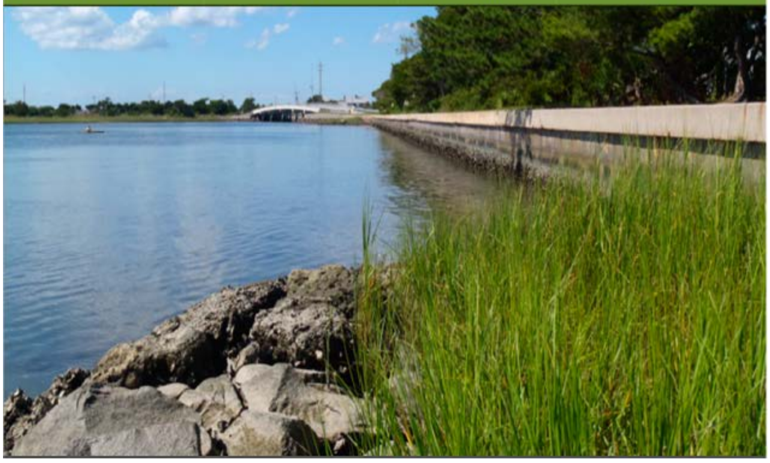

Figure 1. Comparison of costs and benefits of using built or NI for coastal protection

Source: Sutton-Grier, et al., 2018

There are three main categories of advantages resulting from NI implementation: land security, climate regulation and water security. It should be noted that all categories are intertwined with one another and that no category has mutually exclusive benefits.

1.2.1 Land Security

- *Protection against erosion* is an NI benefit specifically in cases such as reefs. Coral reefs act as the first line of defence from the damaging impacts of waves on coastlines, reducing more than 85 per cent of incoming wave energy (Alliance Development Works, 2012, cited in UNEP, 2014). This helps in coastal stabilization by mitigating the flooding and erosive effects of storms. Apart from reefs, reforestation and afforestation are important actions to increase forest cover, an NI that can help protect hill slopes, riverbanks and shorelines from erosion, landslides and associated water pollution. This is important if we consider the role of wetlands as "sinks" for sediments, meaning that it is important to focus on potential sediment "sources" or ecosystems on high-gradient terrain (UNEP, 2014).
- *Flood management* occurs during the construction or maintenance of a variety of NIs. In generating a water retention site (as seen the "water security" section), flood risk and land damage are mitigated. An example of NI for flood management is reconnecting rivers to floodplains.
- *Drought mitigation* occurs when greater water retention reduces soil salinization, making drought less of a risk. NI, such as wetland conservation/construction, can also help to mitigate drought by regulating the release of water from natural storage features such as soil, groundwater, surface water and aquifers.
- *Biodiversity preservation* occurs through the conservation or rehabilitation of natural sites, which enriches habitats for fauna and flora. As these species are allowed to live and prosper, they grant human populations additional benefits not only in land security but also in climate regulation through carbon storage/sequestration. NI solutions, such as those providing shade (i.e., re/afforestation), can also be implemented to reduce the temperature of waterways affected by thermal pollution, protecting aquatic ecosystems and their provision of ecosystem services, such as water purification.

1.2.2 Climate Regulation

- *Carbon storage/sequestration* occurs in any natural site with greenery, especially in wetlands and forests. There are no grey infrastructures in the world that can economically do what these sites do, which is remove carbon from the atmosphere.
- *Global cooling mechanisms* are, again, a common offering of any green space. Trees have proven, natural and reliable effectiveness in shading and cooling. This, along with carbon sequestration, allows for global temperature increases to be managed.

1.2.3 Water Security

Water management for water security ties all of the categories of NI benefits together, as it produces a wide array of co-benefits.

- *Water quality and potability regulation* are particularly emphasized as benefits of NI and are major points of interest for investors. NI can purify polluted water (from both point and nonpoint sources), protect groundwater from future contamination and enhance pre-existing water treatment facilities. Water filtration and chemical conversion occur through the trapping of sediments and the removal of toxins and heavy metals. Via bioretention and infiltration, NI can relieve the pressure on existing water treatment facilities by enhancing water capture and slowing the release of contaminants. Wetlands and riparian buffers are specifically known for their regulation of TSS, phosphorus and nitrogen levels (McDonald, 2015; UNEP, 2014).
- *Water retention and supply regulation* are also factors that need to be considered when assessing NI, given that water provision is driven by natural ecosystems. NI can help to increase or sustain water supplies by increasing wetland/soil infiltration and storage, as well as aquifer recharge. This provides a wide array of socioeconomic benefits to society. While grey infrastructure often helps with distribution of potable water, NI benefits extend far beyond. They allow for groundwater recharge and assist in maintaining water levels of aquifers. Types of NI that can be implemented to generate these benefits include re/afforestation and forest conservation, reconnecting rivers to floodplains, wetland preservation or construction, water harvesting, green spaces and even the use of green-grey infrastructures, such as permeable pavements (UNEP, 2014).
- *Water flow regulation* is important for the moderation of extreme events, particularly floods, one of the most regularly occurring and expensive natural disasters. NI helps maintain natural flow patterns and reduces peak flows during heavy precipitation or flood events (UNEP, 2014). Overall, different NI solutions can be applied for different types of flooding:
    - For riverine flood control, NI can help in flood mitigation by increasing the water storage capacity of the watershed through forest management. Forested areas intercept rainfall and increase infiltration, increasing the capacity of ecosystems to store water in porous soils and debris. This leads to a delayed release of water into surface and groundwater bodies. Also, for riverine flood control, riverine buffers can increase river channel capacity, reducing flow velocity and pressure on levees (UNEP, 2014). Both of these NI components help maintain natural flow patterns and reduce peak flows during flood events, which is essential for preserving the integrity of riparian and in-stream habitats and the wildlife and fish populations that depend on them (Hanson, Talberth, & Yonavjak, 2011).
    - In cases of flooding of urban areas due to stormwater runoff, green spaces, roofs, permeable pavements and water harvesting can be used for flood mitigation. By diverting runoff in urban settings, risks of sewer overflow and contamination will be avoided.
    - Coastal flooding management is an example of the limitation of grey infrastructure in terms of simply shifting the risk elsewhere. Coastal flooding has traditionally been managed in less effective ways, since dikes, levees, seawalls and jetties merely shift the problem either to another area nearby

or further down the coast. Once inundation has occurred, issues such as land destruction and water salinization follow. Alternatively to coastal grey infrastructure, mangrove forests, marshes, dunes and reefs have all proven to be the most efficient means of mitigating flood risk and all other associated risks, because they divert pressure away from the land or the coast (Watkiss, Downing, & Dyszynski, 2010; UNEP, 2014).

1.3 Case Studies of NI Projects

The primary benefits of NI are in water management ecosystem services provision, yet the delivery of additional ecosystem services create many co-benefits beyond the water sector (UNEP, 2014). The following examples highlight the extent of the value of NI by illustrating this provision of co-benefits.

1.3.1 Wetland Restoration/Conservation

Primary benefits (UNEP, 2014): Wetlands can support grey infrastructure for water treatment, water supply, drought mitigation, flood control and biodiversity conservation (water temperature and quality control).

Example:

The Muthurajawela wetlands in Sri Lanka retain high loads of domestic and industrial wastes as well as sediment and silt loads from surrounding and upstream sources. This protects water quality in the downstream Negomo Lagoon by facilitating sediment deposition before the water enters the lagoon. The Muthurajawela wetland also contributes to flood mitigation during the rainy season through its ability to retain high volumes of water and discharge them slowly into the Negomo Lagoon.

Example (International Union for Conservation of Nature and Natural Resources [IUCN], 2016):

The main purpose for the restoration of the Kabukuri-numa wetlands in Japan was for their recognized value in managing disaster risk, specifically their function as a flood-control basin (Kurechi, 2007)

Co-benefits: Wetlands can replace grey infrastructure if we consider their cost-competitiveness in terms of the wide range of socioeconomic co-benefits they provide. Beyond their direct water quantity and quality-related benefits, wetlands:

1. Provide important cultural services such as aesthetic enjoyment and tourism (TEEB, 2011)
2. Support livelihoods through their provisioning services (e.g., fisheries) (UNEP, 2014)
3. Provide and regulate habitats for a number of species, resulting in some of the highest levels of biodiversity conservation among all NI solutions (UNEP, 2014)
4. Contribute to climate change mitigation through carbon storage and sequestration.

Example:

The most important co-benefit of the Muthurajawela wetland is the impact of water quality on the productivity of fisheries in the Negombo Lagoon, which is an estimated 150 kg/hectare/year, contributing to the livelihoods of over 3,000 families from 26 villages. The lagoon alone is said to be valued at about LKR 20 million per year, due to fish production and further ecosystem services that are provided. There is heavy reliance on such nature-based services in the surrounding areas, as roughly 70 per cent of the population is considered rural (Emerton & Kekulandala, 2003).

Example (IUCN, 2016):

In the conservation effort to return the Kabukurinuma to its original wetland status, the number of migratory geese in these wetlands has increased threefold. This is now seen as an important indicator of a healthier landscape as well as a new ecotourism opportunity during non-farming months. Another important co-benefit is the economic opportunities that have arisen. Despite a decrease in crop yields following the transition to new agricultural practices (as a part of the wetland restoration effort), successful eco-labelling of rice as “premium rice” has almost doubled its retail price and a local sake brewery is purchasing this rice at a premium cost.

1.3.2 Wetland Construction

Primary benefits (UNEP, 2014): Constructed wetlands are artificially created to carry out the same hydrological processes as natural wetlands. Therefore, just like natural wetlands, the main benefits of constructed wetlands include improved water quality, regulation of water supply, drought mitigation and flood control. Also, just like in natural wetlands, vegetation and sediments in constructed wetlands provide a healthy ecosystem for the microbes required to filter pollutants and sediments; however, these attributes are optimized in the design of artificial wetlands (Canadian Water Network, 2007). This is why constructed wetlands are said to function as biological wastewater treatment "technologies" (UNEP, 2014), either as support or a replacement of grey infrastructure for water treatment. Their main primary benefits are nutrient pollution control of domestic, urban (sewage) and industrial wastewater, grey water and sludge (Albold et al., 2011).

> ***Example (Downing, Blumberg, & Hallstein, 2013):***
>
> A wetland construction project in North Seadrift, Texas, United States, was pursued as an alternative to North Seadrift's wastewater treatment system, which had exceeded its discharge permit criteria for TSS and required pH adjustments. The constructed wetland has met all discharge requirements for TSS since its implementation, also eliminating algal bloom issues and the need to routinely adjust discharge pH.
>
> **Example (TNC, 2013):**
>
> The world's largest commercial constructed wetlands are found in in Oman. Their purpose is to treat water from the oil production operations in the Nimr oil fields that would otherwise be dumped in aquifers.

Co-benefits (UNEP, 2014): In addition to their main water management benefits, constructed wetlands can provide habitats for biodiversity preservation, which also supports important cultural services such as community and recreational benefits (TEEB, 2011). Depending on the size of the constructed wetland, carbon sequestration and storage, as well as income generating opportunities (e.g., tourism), may be additional co-benefits.

> ***Example (The Nature Conservancy, 2013):***
>
> Co-benefits in North Seadrift include a positive impact on ecosystems. The elimination of algal blooms allows aerobic wildlife to thrive. The project also provides an educational opportunity and other soft benefits to Dow employees and local community members in terms of aesthetic enjoyment and other recreational opportunities.
>
> ***Example (The Nature Conservancy, 2013):***
>
> The constructed wetlands in Oman treat over 95,000 m^3 of wastewater per day, providing habitats to fish and hundreds of migratory bird species. Furthermore, they have contributed to a significant reduction in the carbon footprint of the wastewater treatment plant, with carbon dioxide emissions reduced by approximately 90 per cent.

1.3.3 Coastal Wetlands

Primary benefits (UNEP, 2014): The most important benefit of coastal wetlands (mangroves, salt marshes) is their function as natural barriers between the sea and the land, which mitigates the impact of storm surges and floods. For every mile of wetland, storm surge is reduced by 8–20 cm (Secretariat of the Convention on Biological Diversity, 2013), as coastal wetlands dissipate incoming tidal energy in intertidal zones. Coastal wetlands help protect infrastructure and human health along coastlines.

Example (Rao et al., 2012):

Lami Town, a coastal town in Fiji, is very susceptible to storm surges, flooding and erosion, as it is predominantly built over shallow soils on sloped hills. A cost-benefit assessment of Lami Town compared engineered options to NI-based alternatives for storm protection, such as mangrove conservation. Benefits were estimated to range from FJD 8 to FJD 19.50 for every dollar spent on NI-based coastal adaptation, with an assumed damage avoidance of 10–25 per cent. These values include avoided health costs, damage to businesses and households, and damage to ecosystem services. Engineered options (grey infrastructure) only reaped benefits of FJD 9 but have an assumed damage avoidance of 25–50 per cent. Therefore, the best plan based on cost-to-benefit and assumed level of avoided damage was established to be a combination of engineered and NI-based alternatives, using the more efficient, engineered measures in areas of particular economic importance.

Co-benefits (UNEP, 2014): Mangroves and salt marshes are vital in the mitigation of climate change through their ability to store carbon. Degradation of coastal wetlands would release 2,000 $tCO_2/km^2/yr$ (Russi et al., 2013). Furthermore, they are key biodiversity hotspots, especially in the tropics. Mangroves host up to around 90 per cent of marine species at some point in their life cycle. Lastly, they contribute to a range of economic factors that are the source of income for millions. Through their ability to prevent saltwater intrusion and provide the ideal breeding and nursery grounds, mangroves support a wide variety of birds, fish, shellfish and mammals. They are also important in the export of organic matter to offshore fisheries, with 80 per cent of the world's fish catch dependent on mangroves. Lastly, mangroves also produce raw materials for fuelwood, construction, industry and medicine (Lewis, 2001). Evidently, coastal wetlands are not only vital natural defence barriers between the sea and the land but are also important habitats for biodiversity and people.

Example (Rao et al, 2012):

Co-benefits of coastal revegetation for the people of Lami Town include the wide range of secondary ecosystem services provided, such as recreational value and protection of cultural heritage. By protecting the habitat's important species, they are protecting resources for future generations and potential scientific opportunities. Furthermore, they are also enhancing economic opportunities by supporting inshore artisanal fisheries.

2.0 Typologies of NI

This section reviews literature about the NNBI components that IISD has identified for SAVi. Freshwater wetlands are analyzed at this stage and more types of NNBI will be added as the SAVi model is expanded in the next months and years.

2.1 Freshwater Wetlands

Wetlands, as a specific example of NI, were first highlighted as important for water purification and flow management in 1994 (da Silva & Wheeler, 2017; Sajaloli, 1996). Since then, wetlands have proven effective in both water retention and water quality, namely potability. These functions are important not only for water sanitation and supply, but also for drought mitigation and flood management. As previously mentioned, water security ties all of the categories of NI benefits together.

Indeed, wetlands are considered to be one of the more versatile and representative categories of NI. For example, through their efficient means of purification, filtration, nutrient cycling and carbon storing, wetlands are considered essential for the augmentation of provisioning services such as food, water and timber (Russi et al., 2013). The regulatory ecosystem services of wetlands for water security are cost-competitive, as they have the capacity to replace and/or support traditional infrastructure for water treatment and supply.

The array of ecosystem services provided by wetlands contributes to the achievement of multiple Sustainable Development Goals (SDGs), such as SDG 6 (clean water and sanitation), SDG 13 (climate action) and SDG 14 (conserve and sustainably use the oceans, seas and marine resources).

On the other hand, as a consequence of the increasing demand for water, food and land, wetlands are the most rapidly declining ecosystems in the world. The intensifying impacts of climate change generate additional pressures, and anthropogenic climate change mitigation measures often increase instead of decrease pressure on wetlands (Wetlands International, 2018).

This in-depth review distinguishes between two distinct types of investments in wetlands: the restoration of natural wetlands and the construction of artificial wetlands.

1. **Wetland Restoration/Conservation** refers to the renewal of wetlands that have been drained or lost as a result of human activities. Wetlands that have been drained and converted for other uses (e.g., agriculture) often retain soil and hydraulics characteristics and can therefore be restored (EPA, 2014). In general, the best way to prevent further loss of ecological and economic value due to degradation of wetlands is by eliminating the pressures driving this degradation (e.g., designating wetlands as conservation sites). The restoration of wetlands is often an expensive and difficult process.
2. **Artificial Wetlands** refers to constructed wetlands that are created artificially with the aim of simulating the hydrological processes of natural wetlands. They usually take the form of shallow depressions with dense and diverse vegetation coverage (Centre for Watershed Protection, 2007). Constructed wetlands can function as biological wastewater treatment "technologies," either as an enhancement or a substitute to conventional treatment plants. There are two different types of artificial wetlands, free water surface (FWS) wetlands and subsurface flow (SSF) wetlands. In FWS wetlands, plants float on the surface of the waterbody. Plants in SSF wetlands grow in a substrate, and the wastewater level is kept below the surface. SSF wetlands are a viable option for wastewater treatment in Africa, as it prevents the breeding of malaria mosquitoes (Kimwaga, Gastory, Nyamboge, & Mutabazi, 2012).

Box 1. Wetlands and their functioning

Constructed and/or restored wetlands are engineered nitrate, phosphorus and sediment treatment systems that function under a variety of conditions. If positioned strategically, wetlands can significantly improve water quality and reduce nutrient leakage to ground and surface water bodies (Tyndall & Bowman, 2016; UNEP, 2014).

Wetlands slow down the movement of water and allow sediments in runoff water to settle. Perennial vegetation in and around wetlands has the capacity to absorb excess nitrogen and phosphorus from drainage water and hence reduce loadings. Artificial wetlands with the purpose of water purification intercept tile drainage and microbially denitrify nitrate into nitrogen and release it into the air in gaseous form (Tyndall & Bowman, 2016).

Wetlands are important for land security, water security and climate regulation, through their provisioning and regulatory ecosystem services that lead to enhanced flood control, water supply and carbon sequestration. On this, wetland degradation leads to increased carbon emissions—or, rather, less carbon sequestration. Estimates suggest that seagrass meadows can store between 4 and 20 Pg of carbon (Fourqurean et al., 2012). Within a 50-year time frame, it has also been suggested that, in the absence of wetlands, 2,000 $tCO_2/km^2/yr$ of carbon can be released into the atmosphere (Crooks et al., 2011; Duarte, Middelburg, & Caraco, 2005).

In summary, healthy wetlands provide the following main benefits:

- *Water supply regulation for flood management and drought mitigation*: Wetlands have the ability to retain water and release it gradually, which is especially useful during bouts of flooding or drought. This increased resilience to flooding mitigates potential risks due to the destruction of grey infrastructure and potential harm to people.
- *Stormwater management*: Wetlands can retain significant levels of stormwater runoff, helping to regulate water quantity and contributing to groundwater recharge. Constructed wetlands can reduce 5–10 per cent of the volume of incoming runoff, thus mitigating flood risk (Centre for Watershed Protection, 2007).
- *Water quality regulation*: Wetlands can naturally enhance water quality by filtering effluents and absorbing pollutants. Microorganisms in the soil help to break down waste, reducing the level of water pollution. Thus, wetlands can provide clean water for a variety of uses, like drinking, energy, etc. (TEEB, 2011; Tyndall & Bowman, 2016).
- *Water purification and biological control*: Wetlands have the inherent ability to trap sediments, thereby reducing the volume of sediments transported downstream (Russi et al., 2013). Wetland vegetation and sediments provide healthy ecosystems for microbes, which assist in filtration in tandem with pollutants attaching to sediments. The pollutant removal rates of constructed wetlands can be as high as 85 per cent removal of TSS, 75 per cent removal of phosphorus, 55 per cent removal of nitrogen and 45 per cent removal of carbon (Centre for Watershed Protection, 2007; Jordbruksverket, 2010; Tyndall & Bowman, 2016). Due to these benefits, wetlands are often constructed to provide secondary and tertiary wastewater treatment steps for the generation of high-quality water (EPA, 2000).
- *Carbon dioxide absorption*: Wetland vegetation and the buffers surrounding wetlands then serve as carbon sinks. Through photosynthesis, this vegetation breaks up carbon dioxide and releases oxygen in return. In addition, by providing wastewater treatment services, wetlands potentially reduce the amount of carbon dioxide emissions from wastewater (Mitsch et al., 2012; Wetlands International, 2018).
- *Co-benefits of wetlands*: The additional benefits of restoring or constructing a wetland include enhancing biodiversity, supporting jobs in fishing and tourism, and assisting in climate change mitigation (UNEP, 2014).

Examples of Benefits of Wetlands:

Mangroves in Thailand

Natural infrastructures are often less expensive than grey infrastructure. Mangroves in Thailand provide approximately USD 10,821/ha in coastal protection against extreme weather events, USD 987/ha for fish nurseries and USD 584/ha for both timber and non-timber forest products (Barbier, 2007; TEEB 2013).

Fynbos Biome, Western Cape, South Africa

Within the Fynbos Biome of South Africa, the water treatment capacity of wetlands was estimated based on the costs of enacting the same services with grey infrastructure. It was recorded that, with grey infrastructure, it would cost approximately USD 12,385/ha per year, making NNBI cost-competitive (Turpie, 2010).

Example of Costs of Wetland Loss:

Coastal wetland loss in the United States

Coastal wetlands in the United States are estimated to currently provide USD 23.2 billion per year in storm protection services alone (Russi et al., 2013). A loss of one hectare of such wetland is estimated to correlate to a USD 33,000 increase in storm damage (Constanza et al., 2008).

Examples of Benefits of Wetland Restoration:

Peatland restoration in Mecklenburg-Western Pomerania, Germany

In Mecklenburg-Western Pomerania alone, 97 per cent of the 300,000 ha of peatlands have been drained. Over 930,000 ha were drained across Germany. Due to the clear carbon emissions that this drainage led to, active efforts were made to restore just under 30,000 ha of these peatlands, avoiding emissions of 10.4 tCO_2 per ha (Schäfer, 2009). Additionally, costs of EUR 21.7 million every year, on average EUR 728 per hectare of restored peatlands, are avoided due to the presence of these restored peatlands. Carbon storage is a significant service, as it provides climate change mitigation (Federal Environment Agency, 2007). There is also a series of co-benefits generated from peatland conservation or restoration sites, including biodiversity conservation. With the conservation of these sites, a variety of birds have the ability to reside within these lands, thus adding to the natural beauty, which contributes to tourism. Paludicultures allow for provisioning services, thus providing commodities as well (TEEB 2013).

Peatland restoration in Bellacorick, Ireland

The peatlands of Bellacorick were restored in 2009 in hopes of raising the local water table, remediating the land and thus restoring the carbon sequestering site. These restoration efforts avoided carbon losses equating to EUR 1,506 per ha of peatland restored and led to a gain of EUR 118 per ha per year for the average net carbon sequestration (Wilson et al., 2012).

Mangrove restoration in Senegal

Mangroves are a precious asset in places such as the Sine Saloum Delta, where 45,000 ha of them were lost due to drought, reductions in fish stocks and increases in water salinity in the 1970s. These issues have since been exacerbated, leading to a reduction in the quantity of reliable and potable water sources and increased deforestation. The socioeconomic impacts extend even further, as food security must also come into question. Restoration efforts were made in 2008 by Oceanium, a Senegalese NGO, which replanted 163 ha of mangroves in the surrounding area. In 2009 these efforts continued with the support of Danone and 1,700 ha more were replanted. These efforts were continued into 2010 and 2011. This was registered under the Clean Development Mechanism of the United Nations Framework Convention on Climate Change (Russi et al., 2013).

Example of Costs of a Constructed Wetland:

In Washington, DC, a wetland was constructed to cope with water being contaminated due to combined sewer overflows. In constructing a wetland rather than a type of grey infrastructure, the city saved USD 26 million in construction costs and annually saves USD 1.6 million in operational costs. By combining the use of various grey technologies already in place (i.e., tertiary treatment with UV disinfection systems, with a primarily green foundation), the city was able to optimize the cost-effectiveness of wetlands for their specific context. The water that is being discharged into Hawkins Creek is now above any set water quality standards (UNEP, 2014).

2.2 Shortcomings and Risks Related to NI

Although wetlands provide multiple services, if constructed for a specific purpose, it is difficult to define exact performance outcomes. For example, for water quality regulation, the range of nutrients absorbed can vary, depending on the type of wetland used, its primary purpose and its management (Jordbruksverket, 2010; Tyndall & Bowman, 2016).

Further, nutrient absorption rates in wetlands are temperature dependent, which implies: a) that nutrient absorption differs on a seasonal scale and b) that wetlands might not be feasible in extremely cold climates. While the detention time might be compensated by increasing the size of the wetland, it reduces the cost-effectiveness and/or technical feasibility of the project (EPA, 2000).

Land requirements are a determining factor when it comes to the feasibility of artificial wetlands, while grey treatment technologies often only require a fraction of the land to provide the same level of service (EPA, 2000; Jordbruksverket, 2010; Tyndall & Bowman, 2016).

These are some of the reasons why wetlands are often used for secondary or tertiary wastewater treatment, while primary treatment is done in centralized wastewater treatment facilities (EPA, 2000). Wetlands are hence used as "supplementary" rather than primary service providers.

In addition, the lack of knowledge and technical guidance for policy-makers and implementers leads to a situation in which "familiar solutions" are prioritized, as processes, permit requirements and performance specifications are well known (World Business Council for Sustainable Development [WBCSD], 2017).

Overall, policy procedures and permit requirements are not yet well defined for wetlands and require more time and resources to obtain, increasing the risk of successful and timely project implementation for investors.

3.0 Typologies of Green Infrastructure for Urban Water Management

Green infrastructure (GI) refers to natural and/or manmade elements that provide, improve or restore ecological and hydrological functions and processes to manage wet weather impacts (Sustainable Prosperity, 2016). An example is stormwater. The term "green infrastructure" was first used by the Florida Greenway Commission (1994) in their endeavour to emphasize that the state's conservation area creates an interconnected system of GI components that provide crucial services, in contrast to those provided by grey infrastructure components (da Silva & Wheeler, 2017; Florida Greenway Commission, 1994).

Most of the currently installed stormwater management systems consist of grey infrastructure components, including pipes, pumps and culverts (Canadian Water Network, 2015; Sustainable Prosperity, 2016). Grey infrastructure often contributes to a specific purpose, such as the management of stormwater in urban areas, but does not necessarily support the mitigation of stormwater-related externalities, such as peak flow. This is why, in recent years, GI components are increasingly being incentivized in recognition of their beneficial effects in absorbing large quantities of stormwater through the increase of permeable surface, hence reducing peak flow as well (EPA, 2014). To capitalize on the benefits of GI in boosting urban resilience in the face of future climate change impacts, a variety of cities are incentivizing the use of GI components for urban water management (AECOM, 2013; City of Philadelphia, 2017; EPA, 2014; Philadelphia Water Department, 2017; Sustainable Prosperity, 2016). Tables 2 and 3 provide an overview of currently used practices and GI-related benefits.

Table 2. GI practices and related benefits

Benefit	Reduces Stormwater Runoff											Improves Community Livability						
	Reduces Water Treatment Needs	Improves Water Quality	Reduces Grey Infrastructure Needs	Reduces Flooding	Increases Available Water Supply	Increases Groundwater Recharge	Reduces Salt Use	Reduces Energy Use	Improves Air Quality	Reduces Atmospheric CO_2	Reduces Urban Heat Island	Improves Aesthetics	Increases Recreational Opportunity	Reduces Noise Pollution	Improves Community Cohesion	Urban Agriculture	Improves Habitat	Cultivates Public Education Opportunities
Practice										CO_2								
Green Roofs	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Maybe	Yes	Maybe	Maybe	Yes	Yes
Tree Planting	Yes	Yes	Yes	Yes	No	Maybe	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Maybe	Yes	Yes
Bioretention & Infiltration	Yes	Yes	Yes	Yes	Maybe	Maybe	No	No	Yes	Yes	Yes	Yes	Yes	Maybe	Maybe	No	Yes	Yes
Permeable Pavement	Yes	Yes	Yes	Yes	No	Maybe	Yes	Maybe	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes
Water Harvesting	Yes	Yes	Yes	Yes	Yes	Maybe	No	Maybe	Maybe	Maybe	No	No	No	No	No	No	No	Yes

Yes Maybe No

Source: Adapted from Center for Neighborhood Technology, 2010.

Table 3. GI practices and related benefits

	Ecosystem services (TEEB classification)																
	Provisional				Regulating							Supporting		Cultural			
GI solution	Water supply	Food production	Raw materials	Medicinal resources	Temperature control	Carbon Sequestration + storage	Moderation of extreme events	Water purification	Erosion control (incl. shoreline)	Pollination	Biological control	Habitats for species	Maintenance of genetic diversity	Recreation	Tourism	Aesthetic/cultural value	Spiritual experience
Re/afforestation and forest conservation	■	□	□	□	■	□	■	■	■	□	■	□	□	□	□	□	□
Riparian buffers		□	□	□	■	□	■	■	■	□	■	□	□	□	□	□	□
Wetlands restoration/ conservation	■	□	□	□	■	□	■	■	□	□	■	□	□	□	□	□	□
Constructing wetlands	■				■	□	■	■	□								
Reconnecting rivers to floodplains	■	□	□	□	■	□	■	■	■	□	■	□	□	□	□	□	□
Establishing flood bypasses							■					□		□		□	
Water harvesting	■						■		□							□	
Green roofs		□			□		■			□		□				□	
Green spaces (Bioretention and infiltration)	■	□			■		■	■	□			□		□		□	
Permeable pavements	■						■	■	□								
Protecting/restoring mangroves, marshes and dunes		□	□	□	□		■		□	□	□	□	□	□	□	□	□
Protecting/restoring reefs (coral/oyster)		□					■		□		□	□	□	□	□	□	□

Note: Dark blue cells mark services directly related to water management issues, while light blue cells mark co-benefits
Source: UNEP, 2014.

3.1 Green Roofs

Green roofs can be used for a variety of reasons, for example to satisfy planning/permit constraints, mitigate stormwater impacts, support wildlife or biodiversity, provide recreational space, offer additional energy savings or for aesthetic purposes (Bauder, 2018). There are two types of green roofs: intensive or extensive. Intensive is the bolder of the two, as it has more resilient, deeper rooted vegetation, while extensive has more shallow root systems. Table 4 illustrates the different components used to manufacture a green roof structure, for both intensive and extensive designs. Each option fulfills a purpose, and the choice of materials typically depends on the type of vegetation specified and how the required balance between water retention and drainage is achieved to meet the irrigation requirements of the vegetation (Bauder, 2018).

Table 4. Components of green roofs and their function

Component	Description
Vegetation and substrates	The different vegetation options will require different depths of substrate (growing medium) in order to support the plants and their root structures. Intensive roofs require careful design considerations and the desired planting scheme will reflect that of a ground-level garden or recreational space.
Filter layer	This layer is a polypropylene geotextile fleece that prevents substrate fines and sediment from being washed into the water storage or drainage component. The pore size is around 0.13 mm.
Water storage/ drainage layer	This layer helps to maintain the balance between the levels of water to be held on the roof to support the vegetation while allowing the surplus amount to drain away so that the substrate doesn't become waterlogged. The water storage cells can be filled with coarse gravel or crushed brick to increase the compressive capabilities of the buildup.
Protection layer	This layer delivers protection against damage to the waterproofing system that lies beneath the green roof. The layer can be of varying thicknesses, selected and specified to cope with possible levels of mechanical damage that the waterproofing could be subjected to.
Separation layer	This layer ensures that the building structure and its waterproofing can move independently of the green roof, allowing for movement such as thermal expansion without shear forces created by the weight of the green roof restricting it.

Source: Bauder, 2018.

The benefits from the implementation of green roofs are a 15–45 per cent savings on energy consumption and up to 60 per cent of stormwater management reduction per year. During storm events, water retention by green roofs has been up to 90 per cent during smaller storms and no less than 30 per cent during larger storms. The net present value of a green roof is approximately 40 per cent higher than a typical grey roof. Even though initial investments are higher, investing in NI is more economically advantageous in the long run (UNEP, 2014).

According to the literature (Bauder, 2018; EPA, 2014; Feng, 2018), additional benefits of green roofs include:

- Compliance to building codes (e.g. LEED, MINERGIE)
- Satisfaction of planning constraints
- Mitigation of stormwater
- Mitigation of urban heat island (UHI) effects
- Improvement of air quality
- Support for a wildlife or biodiversity solution
- Provision of recreational space with public access
- Energy savings: green roofs provide better insulation and, in addition, solar photovoltaic units are up to 10 per cent more efficient on green roofs
- Aesthetic purposes

Positive externalities: Co-benefits of green roof applications include air quality improvements, reductions in noise pollution, carbon sequestration and aesthetic value (UNEP, 2014).

Example of Benefits of Green Roofs:

Chicago, a Heat Island

The UHI effect occurs in built urban areas. According to the U.S. EPA (2018b), cities with one million or more citizens are often characterized by an annual mean temperature that is approximately 1–3°C higher than its surrounding rural areas. Chicago had long suffered from issues surrounding the UHI effect, which can include increased heat-related illness, air conditioning costs, energy usage and GHG emissions, and reduced water quality and resultant algal bloom potential. In order to combat the UHI effect, Chicago implemented a pilot project to test the effects of green roofs, which have been able to retain 75 per cent of runoff from a 25 mm storm, while also reducing albedo effect (UNEP 2014).

3.2 Green Spaces

Green spaces such as rain gardens and bioswales refer to areas of land covered with vegetation, creating the basis for bioretention. Within urban areas, green spaces constitute critical environmental capital that is, once developed, difficult to replace due to the multiplicity of benefits it provides. The benefits provided and the pathways to follow to harness them must be properly understood by policy-makers and urban planners to ensure strategic planning and development (Gill, Handley, Ennos, & Pauleit, 2007).

Urban green spaces such as domestic gardens, parks and woodlands provide a multitude of benefits to human urban populations and a vital habitat for wildlife (University of Leeds, 2015). Among the benefits provided by green spaces are:

- *Flood mitigation and water quality improvements*: Green, vegetated surfaces are able to intercept and absorb water and hence reduce the total peak flow volume of precipitation events. The reduction in peak flows also reduces pollution wash-off from urban surfaces, which reduces the total pollution loads in stormwater (University of Leeds, 2015).
- *Temperature regulation*: Temperatures in urban areas are typically higher compared to the surrounding rural areas, also known as the UHI effect, which is caused due to higher absorption rates of solar energy through building materials. Urban green spaces reduce the UHI effect by providing shade and by cooling the air through evapotranspiration (Gill, et al., 2007; University of Leeds, 2015).
- *Biodiversity conservation*: Urban areas typically host a less diverse range of plants and animals compared to the surrounding rural areas. Green areas such as parks, woodland regions or even roundabouts provide a habitat for numerous plant, insect and bird species. Furthermore, green spaces can serve as "wildlife corridors" by connecting larger parks to ecosystems outside the city, allowing plants and animals to migrate (University of Leeds, 2015).
- *Air quality improvement and carbon storage*: Poor air quality is a serious threat to human health, causing problems for the respiratory system and cardiovascular diseases. Trees and shrubs have multiple impacts on air quality. They can improve air quality by removing both particles and gases from the air; particles stick to the surface of the leaves, and gases are taken up through pores on the leaf surface. Trees with complex, ridged or hairy leaves (such as pines) tend to capture more particles than trees with broader, smoother leaves (University of Leeds, 2015).
- *Energy savings*: Compared to built-up regions in the same town or city, urban green spaces are on average 1°C cooler during both the day and night time (Bowler, Buyung-Ali, Knight, & Pullin, 2010). This cooling effect can extend into the surrounding urban areas (Yu & Hien, 2006). During the summer, this may reduce the need for air conditioning and associated energy use in nearby buildings (McHale, McPherson, & Burke, 2007).
- *Reduced noise pollution*: In addition to the physical infrastructure benefits, the World Health Organization (2017) has found that green spaces are providing an array of health benefits for the urban population. Parks, playgrounds or vegetation in public and private places are central components of this approach and can help to ensure that:

- Urban residents have adequate opportunities for exposure to nature.
- Urban biodiversity is maintained and protected.
- Environmental hazards such as air pollution or noise are reduced.
- The impacts of extreme weather events (heatwaves, extreme rainfall or flooding) are mitigated.
- The quality of urban living is enhanced.
- The health and well-being of residents is improved.

3.3 Water Harvesting

The amount of potential water storage abilities and the potential productive capacities that come from stormwater harvesting are often overlooked. Water harvesting is a means of redirecting stormwater and storing it for later use, generally in some productive capacity, like agriculture, drinking water, etc.

The two main types of water harvesting are referred to as "in-situ" and "ex-situ" storage. In-situ water harvesting consists of water storage occurring in the place of capture (e.g., soil in a landscape that could serve as a collection site). Ex-situ water harvesting consists of water storage occurring in a location outside of the place of capture (e.g., in reservoirs, dams, wells, ponds, cisterns, etc.) (UNEP, 2014).

The most important benefits associated with water harvesting are water supply regulation and flood mitigation. In-situ water harvesting is focused on water supply regulation, as it relies on the holding capacity of soil and thus contributes to groundwater recharge (Wocatpedia, 2018).

Ex-situ water harvesting facilitates both water supply regulation and flood mitigation. Ex-situ harvesting mechanisms reduce stormwater runoff and allow for increased storage and productive capacities. In urban settings, this flood mitigation also implies the reduction of pollutants in water collection sites, as there will be less likelihood of stormwater, potable water and sewage system water convergence (EPA, 2013).

Positive externalities: Positive externalities resulting from the use of water harvesting systems include soil conservation, climate change resilience, maintained crop productivity and the cultural value of preserving traditional water harvesting knowledge (UNEP, 2014).

Example of Water Harvesting:

Harvesting Ponds in Kenya

The Tana River basin covers an area of 126,028 km^2. The upper basin comprises the slopes of the Aberdare and Mount Kenya mountain ranges in the eastern part of the catchment, from where the watershed's gradient gradually declines until it reaches the Indian Ocean toward the southeast. The Tana River drainage network, the longest river in Kenya stretching about 1,014 km, drains excess water.

Water harvesting ponds are currently being used in the upper, middle and lower parts of the Tana basin as part of a wider ecosystem rehabilitation scheme to promote improved water and ecosystem management. There are many different designs with varying shapes, materials and dimensions. The water concentrated in the ponds originates from the surrounding naturally sloping surfaces or is conveyed from paved surfaces (roads, paths) and channels (cut-off drains). Circular and trapezoidal ponds are the most common design. This solution is applicable in most agro-ecological zones that provide enough rains to fill the reservoir (>400 mm/yr).

The benefits of harvesting water in these ponds include an increase in water flow regulation, erosion control and water supply. The construction of ponds makes water available during dry spells in the rainy season and for a few months after the rains. The water is used to irrigate high-value cash crops and fruit trees, to water the livestock and for domestic use. They are often established near homesteads were they can be easily reached (UNEP, 2014).

3.4 Permeable Surfaces

Permeable pavements are a form of green-grey infrastructure that allows for water be filtered and directed for the purposes of groundwater recharge. The current variations of permeable pavements include pervious concrete and asphalt, permeable interlocking concrete pavers, concrete grid pavers and plastic reinforced grass pavement (Hunt & Szpir, 2006; UNEP 2014). Based on the materials listed above, it may seem as though permeable pavements are merely grey infrastructure, but their ability to mimic and enhance water ecosystem services allow them to be classified as green-grey.

The main objective in installing permeable pavements is to allow for the diverting and directing of water as a means of making it useful for a later date through groundwater recharge. These processes also involve flood mitigation and can reduce storm runoff by 70–90 per cent (Foster, Lowe, & Winkelman, 2011; UNEP, 2014). These structures also promote water purification due to filtration. It has been estimated that 85–95 per cent of TSS, 65–85 per cent of phosphorus, 80–85 per cent of nitrogen, 30 per cent of nitrates and 98 per cent of heavy metals are filtered out through permeable pavements (UNEP, 2014).

The positive externalities that are associated with permeable pavements are the reduced needs for energy for wastewater treatment, air quality improvements, mitigation of the UHI effect and reduced noise pollution levels (UNEP 2014).

3.5 Shortcomings of GI in Urban Areas

Shortcomings of GI in urban areas include side effects, limited efficiency and, perhaps most importantly, the extensive time periods required for monitoring. This last point makes it difficult to see the impacts of NI, which in turn complicates building the business case for NI.

3.5.1 Green Roofs

The most important side effect of a green roof is its structural loading implications (i.e., ensuring the roof is designed to withstand the weight of rain, vegetation, potential access by people and vehicles, within its own load limitations in terms of force exerted on the building). The structural capacity of the roof system can limit the options involved in its design, which affects the purposes it can fulfill.

For example, extensive green roofs are built for stormwater management, but various factors can make native vegetation unsuitable. If structural loading implications requires the green roof to use shallow depths, this may limit the range of suitable vegetation that can be used for the green roof. This, along with heat tolerance, may require intensive irrigation, which contradicts the principles of a green roof project. Indeed, this may make it complicated for buildings with green roofs to become LEED-certified (Luckett, 2009).

Furthermore, green roofs require constant monitoring to ensure that the vegetation and soil are healthy and still able to filter water. As plants reach their pollutant uptake limit, they may have to be replaced. It is of utmost importance to monitor plants growing in areas receiving large streams of pollutants to ensure that they do not pose a threat to human/animal health if these plants are being consumed (UNEP, 2014).

3.5.2 Green Spaces

Cities may implement green spaces as an NI solution for flood mitigation and water quality improvement. Green spaces are often monitored by measuring the fraction of pollutants absorbed, which is when their limited efficiency becomes highlighted. NI is most useful for handling the first increment of rain that falls. During larger rainfall events, the soil becomes saturated, and most rain will flow as surface runoff. Cities must calculate peak flows and runoff volumes in their watersheds to determine the per-unit effectiveness required of the NI. Environmental agencies, such as the U.S. EPA have spreadsheet methods for such calculations, but cannot supply site-specific information (McDonald, 2015).

3.5.3 Water Harvesting

Rainwater harvesting is a strategy that could sustain domestic activities that do not require potable water (i.e., toilet flushing, clothes washing and outdoor activities), which collectively account for approximately 50 per cent of the daily water requirement. However, in homes where the occupancy is more than two people, as well as to avoid seasonal shortfalls (particularly as a result of climate change), rainwater harvesting would not be sufficient and would need to be backed up from public supplies (Booth et al., 2012). This is because water harvesting is dependent on rainfall volume and the size of catchment area/storage reservoir.

Project monitoring is extremely difficult given the episodic nature of storms in some areas. It is also easy to miss the important flux of water needed for the sampling, that which contains the highest pollutant concentration, because it happens over a short period of time. Often, the solution is to focus monitoring resources across fewer sites and invest in a system that is capable of monitoring stormwater quality or quantity continuously over time (Booth et al., 2012).

3.5.4 Permeable Surfaces

An important limitation of permeable pavements is that they are very sensitive to high loads (i.e., vehicle volume) and so cannot be used in locations that are subject to heavy traffic loads (UNEP, 2014).

Permeable pavements must be closely monitored to ensure that pollutants that have infiltrated the pavement do not make their way into the underlying soils and that they do not elevate groundwater levels to the extent that they cause basements to flood (UNEP, 2014).

Lastly, permeable surfaces may be used to slow surface runoff into river channels in order to reduce peak flows and flood risks downstream. As with water harvesting, the low frequency of extreme climate events in certain cities makes monitoring expensive and time-consuming because it is very difficult to deduce how much damage would have been inflicted in the counterfactual case (no NI) (McDonald, 2015).

4.0 Challenges and Opportunities

The main challenges for the implementation of NI are presented in Table 5. These are discussed in more depth in the next sections.

Table 5. Risks to project financing and O&M

	Grey infrastructure	Green infrastructure	Natural infrastructure
Regulatory			
Changing sustainability standards	x		
Nature conservation policies	x	x	
Uncertainty of policy support for GI		x	
Market			
Water/energy price uncertainty	x		
Material manufacturers (of new sustainable technologies) may not live up to standards	x	x	
Governments hesitant to spend on NI			X
Technical			
Operating costs	x	x	
Extreme weather	x		
Wide array of standards leads to knowledge, data gaps		x	X
Use of new technology leads to increased costs	x	x	
Use of new technology increase risk of failure	x		
Social Pressure			
Pressure to set/adopt higher standards	x		
Attitudes of investors changing toward sustainability	x		
Failure to meet desired standard creates legal/ brand issues	x	x	

Next to the obstacles faced on institutional and policy levels, NI solutions pose significant challenges to businesses (WBCSD, 2015, 2017). Labour requirements might be different, and often stakeholders have the final say related to future business endeavours. The implementation or use of NI alternatives requires businesses to think beyond the conventional business case, which entails the valuation of ecosystem services and appreciating and handling uncertainty. Nevertheless, there are solutions, or opportunities, to reduce uncertainty and knowledge gaps related to NI.

In addition to institutional inertia and a lack of evidence to sufficiently support the advantages of NI, each type of NNBI has its own specific inherent risks. Some of the risks related to NNBI are directly related to the proper functioning, and hence the financial performance, of natural-based solutions. Table 6 provides an overview of risks related to NI and GI.

Table 6. Risks related to NNBI by infrastructure type

Component	Risks associated	Source
Natural infrastructure		
Wetlands	- Performance affected by low temperatures (Biochemical Oxygen Demand removal, nitrification and denitrification) - Removal rate of coliforms may not be sufficient and supplemental disinfection required - Unequivocal performance specifications for revenue estimation - Potential breeding grounds for mosquitoes and other disease vectors - Bird population can pose risks to air traffic if the wetland is located near an airport - Depending on the methane production rate, wetlands might encounter additional cost under GHG cap-and-trade agreements - Inadequate remediation might result in the need for pre-treatment; wetlands might not be suited to treat highly toxic industrial wastewater; and pollutants might have negative impacts on the wetland reserve	EPA, 2000; Kielmas, 2018; UNEP, 2014
Green infrastructure		
Green roofs	- Failure to attain the energy efficiency levels specified before construction - Failure to attain LEED credits proposed for specification - Water-related damages to the roof through roots growing through the substrate and inliners - Potential flooding and mould growth - Requires constant monitoring to ensure vegetation and soil health, as they may become toxic to humans/animals	Bauder, 2018; Devries, 2011; CCAP, 2011; UNEP, 2014
Green spaces	- Negative downstream impacts as a result of increased water infiltrations - Risk of asthma and allergy	CCAP, 2011; UNEP, 2014
Water harvesting	- Impacts on water balance through impacts on the recharge rates - Downstream ecosystem impacts through changes in water balance - Benefits in terms of water savings depend on rainfall and the size of catchment area/storage reservoir - Rainwater quality may be affected by air pollution, animal or bird droppings, insects, dirt and organic matter - Water bodies can serve as breeding pools for mosquitoes and other insect vectors carrying disease	Hattum & Worm, 2006; UNEP, 2014
Permeable pavements	- Areas with high contaminant and pollutant levels risk groundwater and soil contamination due to the high permeability and limited capacity for purification - May have clogging problems in locations using road salt during winter months - Depending on the materials used, structural integrity might be affected by oil spills from cars	Rodriguez-Hernandez et al., 2015; UNEP, 2017

4.1 Main Roadblocks for the Adoption of NNBI

4.1.1 Cost and Financing

Despite the lower capital and O&M cost for NI, the willingness to provide financing for nature-based solutions still remains low for several reasons.

Inability to quantitatively evaluate and compare project costs (IUCN, 2016)

Uncertainty around the financial performance of NI assets reduces their comparability to conventional grey infrastructure through a traditional cost-benefit analysis. This is in part due to the inherent uncertainty of natural systems and understanding how NI will respond to climate change (Dalton et al., cited in IUCN, 2016). It is also due to the difficulty in assigning monetary values to non-economic factors.

Furthermore, assessment and cost-benefit analyses of NI are site-specific and therefore cannot be globally applied. Few engineers are trained in such site-specific assessments for evaluating NI projects. Overall, this leads to unreliable quantitative analysis, which is an important limitation for those evaluating different infrastructure options.

According to WBCSD (2017), pilots are useful for building confidence within the financial sector, as they are evidence of the technical feasibility and cost-effectiveness of NI approaches. For example:

> ***Example***
>
> Shell and The Nature Conservancy worked together to pilot the use of the living shore concept (including oyster reefs) for protecting oil and gas pipelines from erosion caused by wave energy in the Louisiana delta in the U.S. The pilot will test the technical feasibility of using a nature-based and/or hybrid approach for physical protection and the cost-effectiveness of a nature-based approach compared to grey alternatives (WBCSD, 2017).

High transaction costs (IUCN, 2016)

Given the potential auxiliary benefits of NI, NI projects require coordination across multiple stakeholders. The cost of engaging and negotiating across regulatory jurisdictions and dispersed landowners can be very time-consuming and expensive.

Furthermore, the immaturity of NNBI policy frameworks can have a range of unforeseen side effects (Ozmet, DiFrancesco, & Gartner, 2015) (e.g., multiple permits required, different legal foundations, working across jurisdictions, etc.) that can significantly increase the time and resource intensity of projects and delay implementation and revenue streams.

Long-term horizons (IUCN, 2016)

In general, NI takes longer to reach its full capacity in terms of ecosystem service provision than grey infrastructure alternatives. Particularly in restoration/conservation projects, the ecological processes required to establish the full array of NI benefits, and therefore revenue, may take years, and, in some cases, the NI project may not even be able to generate a revenue stream.

Furthermore, funding is often provided on time horizons that are not long enough for the nature of the project. This makes it difficult to build the business case for NI against grey infrastructure, which has more short-term certainty.

Insufficient financing (IUCN, 2016)

The uncertainty emerging from the barriers outlined above generate the perception that NI projects are riskier than conventional approaches, despite the fact that often the opposite is the case, considering the adaptivity of the asset to climate change impacts (Tyndall & Bowman, 2016; WBCSD, 2017). Therefore, government or long-term investors that could provide investments for NI generally do not do so. This is a problem, considering how difficult it is to determine who should pay for NI.

Small project scale (WBCSD, 2017)

NI projects are relatively small in comparison to grey infrastructure projects. This means that they may simply not be large enough to attract investors who are looking for revenue generation and an attractive risk-adjusted return. Furthermore, it is challenging to quantify risk at an acceptable level for investors, which makes it even more difficult to obtain investor confidence.

Lack of coordination of projects and funding (WBCSD, 2017)

Project financing and implementation is often not coordinated within the countries where the projects are being funded. This is a big challenge, especially in developing countries that are highly dependent on external funding for NI projects. For example, local officials may not even be aware of the projects being funded by external donors, which may hinder the efficiency and sustainability of such projects (WBCSD, 2017).

Lack of revenue streams:

NI projects generally lack any revenue-generating potential, as current business models do not price accurately the services provided by these solutions. Therefore, NI projects need to rely on grants and public resources for their financing needs. However, when NI projects complement revenue-generating grey infrastructure projects, they can be a financially attractive alternative to traditional solutions. This way project finance models can more accurately capture and price their contributions and justify their costs.

4.1.2 Financing Opportunities for NI

According to a report published by the IUCN, activities to facilitate investments in NI entail: a) the identification of economically viable opportunities for NI; b) the communication of successes and challenges to build a literature body surrounding NI; c) institutionalization of the assessment of NI in, for example, water and energy system design; and d) establishment of enabling conditions necessary to inspire confidence in NI as a feasible strategy (Ozmet, DiFrancesco, & Gartner, 2015).

While financing mechanisms for built infrastructure are well established, approaches to financing of NI and valuing related benefits are relatively new (World Resources Institute [WRI], 2013). Economic valuation of the co-benefits of NI is crucial in this respect. Different valuations can be applied for the monetization of services provided by NI solutions. Table 7 illustrates the use of valuation methods for services provided by a constructed wetland.

Table 7. Constructed wetland functions, related economic values and suggested valuation methods

		Wetland function	Good or service provided	Valuation Method
Market benefits		Hydrology / Water Quality	Supply of reusable water	market price
		Fish and Wildlife Habitat	Food and fiber production (harvesting)	market price
			Protection of fisheries / Aquaculture	market price
Non-market benefits	Use Values	Hydrology / Water Quality	Increase of surface water quality	contingent valuation, avoided cost analysis
			Groundwater recharge	contingent valuation, avoided cost analysis
		Fish and Wildlife Habitat	Educational/cultural activities	contingent valuation, travel cost
		Recreation and aesthetics	Recreational activities	contingent valuation, travel cost
		Landscape enhancement	Land development	stated preference methods, hedonic method
	Non-use values	Fish and Wildlife Habitat	Existence and bequest value of biodiversity and biological resources	contingent valuation

Source: Ghermandi, 2005.

Robust financing mechanisms for NI are needed to enable investments on a meaningful scale and to make NI more attractive for entities that mainly rely on opportunistic funding mechanisms such as grants.

An overview of existing and emerging financing mechanisms and potential users is provided in Table 8. Financing mechanisms are divided into direct and indirect government investments, voluntary donations and market-based mechanisms. Direct government investments are direct payments from governments or utilities on behalf of taxpayers or ratepayers. Potential funding sources are bonds, rate or tax increases, and the current government budget. Indirect investments refer to incentivizing investments in natural infrastructure through changes in the tax code, which yields a reduction in tax revenue for the government in return for investments in NI.

Table 8. Existing and emerging financing mechanisms for NI

FINANCE MECHANISM	TYPICAL REVENUE ALLOCATION			TYPICAL USER OF FINANCE MECHANISM	POTENTIAL SCALE OF INVESTMENT
	LAND ACQUISITION	EASEMENTS	LAND MANAGEMENT ACTIVITIES		
Direct Investment by Governments and Utilities					
Rates	X	X	X	Utility	Med
Municipal bonds (revenue-backed)	X	X		Utility	High
Municipal bonds (general obligation)	X	X	X	Government	High
Rates surcharges	X	X	X	Utility	Med
Earmarked Proceeds	X	X	X	Government	Low-High
Development impact fees	X	X	X	Government	Low
Reverse auction	X	X	X	Government	Low
State revolving funds	X	X	X	Utility	Med
Farm bill programs			X	Government	Med
Water Infrastructure Finance and Innovation Authority	TBD	TBD	TBD	Utility	High
Private investment capital		X	X	Utility, Government	Low
Indirect Investment by Governments and Utilities					
Property tax incentives			X	Government	Med
Voluntary Donations by Individuals and the Private Sector					
Voluntary surcharge	X	X	X	Private sector, NGO, Utility	Low
Online crowdsource platforms	X	X	X	NGO	Low
Auction	X	X	X	NGO	Low-Med
Corporate sponsorship	X	X	X	Utility	Low
Market-based Mechanisms					
Nutrient trading		No additional revenue		Government, NGO	Med
Mitigation banking		No additional revenue		Government	Low-Med
Tradable development rights		No additional revenue		Government	Med
Forest banking		No additional revenue		Private sector	Low
Carbon market	X	X	X	Utility, Government, NGO	Low-Med
Certification and labeling programs			X	Private sector, Government	Low

Source: WRI, 2013.

4.1.3 Lack of Knowledge, Technical Guidance and Awareness

According to the WBCSD (2017), the most commonly cited barriers for the implementation of NI is the lack of relevant technical guidance, and this is heavily influenced by policy. The functionalities, benefits and risks related to NI are not well understood by policy-makers, regulators and/or permitting agencies, which leads to a prioritization of grey infrastructure components (WBCSD, 2017). This is a challenge especially for developing countries where the lack of knowledge and technical capacity for implementation of alternative approaches is more prevalent than in developed countries (Jupiter, 2015; Narayan, Cuthbert, Neal, Humphries, & Ingram, 2015).

- *Issues of a vague and immature concept*: NI is not a clearly defined concept and captures diverse natural functions/services that (might) have beneficial anthropogenic value. But the lack of clarity and of systemic approaches make it difficult to apply a quantitative assessment (Sutton-Grier, Wowk, & Bamford, 2015).

- *Institutional inertia and pervasive knowledge gaps (IUCN, 2016)*: Infrastructure decision-makers do not have a clear understanding of the socioeconomic and environmental benefits of NI, and thus do not attempt to incorporate NI into traditional practices. Since the nexus sectors (water, energy, food security) work within their individual frameworks, collaborative opportunities to devise new solutions with NI are overlooked.
- *Accounting issues*: Utilities have struggled to quantify the ecological and economic benefits of NI, a task made more difficult by imperfect science. Even where the case has been made, public utilities work with financial accounting standards that do not enable O&M spending on NI as part of normal business practices, despite the clear benefits.

4.1.4 Limited Policy Support

Lack of knowledge and technical guidance is closely tied to the limited policy support for NI. It is only when NI projects are aligned with policy that barriers to project implementation are lowered. For example, specialists involved with the Washington, DC Stormwater Retention Credit program state that permitting GI is simpler if the project supports the city's regulatory framework for stormwater management (WCBSD, 2017). However, a lack of knowledge and technical guidance may be so prevalent that even existing policy frameworks that support NI are insufficient. When policy-makers, regulators and/or permitting agencies are unfamiliar with NI due to its inherent uncertainty, grey infrastructure is often prioritized.

- *Lack of clarity regarding how NI complies with environmental regulations (IUCN, 2016)*: The variability in performance, time gap between implementation and results, and lack of consistent results creates widespread uncertainty and a lack of clarity regarding how NI aligns with environmental regulations. The high degree of coordination required across different agencies, jurisdictions or levels of government adds to this issue. For example, protection of a municipal water supply through NI may require coordination among federal regulatory agencies responsible for water, environment, wildlife, forest, or agriculture, as well as municipal and state agencies responsible for land use zoning.
- *Lack of policy frameworks that enable permitting and encourage or provide financing for NI*: At present, policy making for NI at the regional level only exists within the EU. In the rest of the world, NI regulatory frameworks must be understood within country-specific policy frameworks or local jurisdictions due to differences in national and local governance, policies and regulations. A nationwide permitting process like that of the EU should be implemented to help streamline permitting across state and federal levels.

  Example

  Prior to 2015, U.S. policy frameworks related to NI included Executive Orders at the Federal level, the U.S. EPA Green Infrastructure Strategic Agenda, and state and local regulations. In 2015, the United States government announced a new memorandum directing all federal agencies to factor the value of NI and ecosystem services into federal planning and decision making. The executive order requires that federal agencies integrate these considerations into their plans and budgets. This will allow for more efficient permitting of NI projects (WBCSD, 2017).

- *Lack of policies explicitly addressing NI permitting*: Current policy frameworks often impede the use of NI solutions; policies that explicitly address permitting of NI are rare, and there are even some policies that either directly or indirectly prioritize non-NI solutions.

  Example

  Policies related to coastal protection in North Carolina require different permits for grey or hard infrastructure and NI, with the latter being more time-consuming and expensive to secure. This creates a disincentive for using NI approaches for coastal protection in NC (WBCSD, 2017).

4.1.5 Permitting Challenges

When there are policy drivers in place for the permitting of NI projects, multiple types of permits may be needed depending on the form of NI being used, its specific goals, where the project is being implemented and the kind of activity or management practices required for the NI project. Furthermore, in the majority of countries, an environmental impact assessment is required in order to get a permit for any type of natural or grey infrastructure project.

To make matters more complex, sometimes different permits are required for grey and NI types addressing the same problem.

Example

In the United States, living shorelines projects often have to apply for an individual Clean Water Act 404 permit, while bulkheads can often be covered under an Army Corps Nation Wide Permit, which are generally granted more quickly (Sutton-Grier et al., 2015).

The complexity of NI permitting is highlighted when it becomes subject to individual interpretation and implementation.

Example

The EU Bird and Habitats Directive establishes a permitting procedure for any plans or projects that are likely to have a significant effect on natural sites. This policy is interpreted and implemented individually by EU member countries and has both catalyzed and impeded the implementation of NI projects. For example, in some countries such as the Netherlands it has been difficult to implement certain NI projects because of the stipulation that specific habitats cannot be transformed, while in the United Kingdom this directive has served as a driver for ecological restoration.

4.2 Policy Interventions

In order to mainstream NI and NNBI, clear and robust policy frameworks that enable permitting and encourage or provide financing for NI projects are paramount (WBCSD, 2017).

As previously discussed, policy making for NI at a regional level currently only occurs in the EU (WBCSD, 2017). Outside of the EU, NI regulatory frameworks are developed according to national and regional governance, policies and regulations. The European Green Infrastructure strategy is focused on restoring or enhancing GI, which is regarded as critical to achieving the goals of other EU policies such as the 2020 biodiversity target and the resource-efficient Europe initiative under the Europe 2020 strategy (Davies, et al., 2015). Existing frameworks such as the Natural Capital Financing Facility (NCFF)[1] can be leveraged for establishing or maintaining NI. The objectives of the NCFF are to supplement traditional grant-based funding in order to reduce the loss of biodiversity and to adapt to climate change, while at the same time demonstrating that natural capital projects can generate revenues or save costs (European Commission, 2014). Table 9 provides an overview of the prevalence of GI principles in global policy discourses.

[1] http://ec.europa.eu/environment/life/funding/financial_instruments/ncff.htm

Table 9. GI principles and their use worldwide

GI principle	UK	USA	Europe	Asia	Other
Sustainability	✓	-	✓	-	-
Multifunctionality	✓	✓	✓	-	✓
Accessibility	✓	✓	✓	-	X
Connectivity	✓	✓	✓	-	✓
Social benefits	-	-	-	-	-
Ecological benefits	-	-	✓	-	-
Economic benefits	-	X	-	-	X
Ecosystem services					X
Scaled (GI principles are applied at a number of scales)	-	-	-	-	X
Integrated policy (GI is discussed within policy to meet varied organizational, spatial and policy mandates)	-	-	-	-	X
Holistic planning approach (reflects social, economic and environmental issues)	-	X	-	X	-
Water management	-	✓	-	X	-
Engineered (proposed invement solutions)	X	-	-	-	-
Climate change	-	-	-	-	-
Coordinated approach to investment	-	-	-	X	X
Identified funding streams	X	X	X	-	X
Promotes long-term benefits	-	-	-	X	X
Urban	✓	✓	✓	✓	✓
Rural	X		-	X	X
Applied/discussed in government policy	X	X	X	-	-
Applied/discussed in regional/local policy	-	-	-	X	-
Government led	X	X	X	-	-
Regionally/locally led	-	-		X	X
Applied discussed in advocacy policy	✓	✓	✓	X	-
Advocacy led	✓	✓	✓	X	X

✓ presents an extensive use of a principle
- a moderate use
X a weak use.

**Through a selective documentary review this figure identifies comparability of green infrastructure thinking between a number of global sources using a content analysis of the publishing documentation and stakeholder/actor discussions. Documentation was reviewed based on: (a) its publication in academic journals, (b) it was based in the practitioner grey (policy, guidance and strategic) literature and was published/adopted by the relevant bodies.*

Table 10 provides an overview of frameworks and initiatives that advocate the use of or provide financing for GI and NI solutions.

Table 10. Overview of policy frameworks and initiatives for NNBI

Continent	Country	Initiative	Link
Europe	EU-28	NCFF	
	Netherlands	The Natural Way Forward Building with Nature	https://www.government.nl/documents/reports/2014/05/20/the-natural-way-forward-government-vision-2014 https://www.researchgate.net/publication/260034582_'Building_with_nature'_The_new_Dutch_approach_to_coastal_and_river_works
	United Kingdom	Natural Capital Committee	https://www.gov.uk/government/groups/natural-capital-committee
	Austria	Biodiversity Strategy Austria 2020+ Lower Austrian Nature Protection Concept ("Naturschutzkonzept")	https://www.cbd.int/doc/world/at/at-nbsap-v3-en.pdf
	Belgium	Biodiversity 2020, Update of Belgium's National Strategy (2013–2020) The Agency for Nature and Forest and the Department for Spatial Planning	https://www.cbd.int/doc/world/be/be-nbsap-v2-en.pdf
	France	Target 5 of the National Biodiversity Strategy 2011-2020 Green and Blue Network (GBN)	https://www.cbd.int/doc/world/fr/fr-nbsap-v2-en.pdf
	Germany	Green in Cities – for a Livable Future, in the federal program, chance.natur	https://www.bbsr.bund.de/BBSR/DE/Veroeffentlichungen/ministerien/BMUB/VerschiedeneThemen/2015/gruenbuch-2015-dl.pdf?__blob=publicationFile&v=2 [in German]
	Spain	The Natural Heritage and Biodiversity Law Strategic Plan for the conservation and rational use of wetlands	http://www.congress.gov.ph/legisdocs/basic_17/HB00527.pdf
Asia	Philippines	National Coastal Greenbelt Action Plan	http://www.bamaquino.com/senate-bill-no-2179-national-coastal-greenbelt-act-of-2014/
Australia	Australia	National Landcare Programme	http://www.nrm.gov.au/national-landcare-program
North America	Canada	Clean Water and Wastewater Fund Program	
	United States	U.S. EPA Green Infrastructure Policy Memos New York City Green Infrastructure Plan	https://www.epa.gov/green-infrastructure/policy-memos https://www1.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml

There is a range of intervention opportunities for governments to incentivize the implementation and financing of NI, leveraging private investment. These are summarized in Table 11.

Table 11. Intervention opportunities for governments to incentivize the implementation and financing of NI

Policy	Definition
Rating Systems and Regulatory Mechanisms	
LEED, SITES, Parksmart	By validating best practices, these frameworks can serve as guides for GI implementation to help cities optimize its benefits. Source: https://www.usgbc.org/articles/green-infrastructure-exploring-solutions-leed-sites-and-parksmart
Zoning codes	Zoning codes can set GI requirements for new construction and renovation projects. These are particularly suited to particular land uses like industrial, residential, etc. Source: http://www.georgetownclimate.org/adaptation/toolkits/green-infrastructure-toolkit/regulatory-tools.html
Building codes	Building codes can set GI requirements and are suited to particular building types regardless of use, including single-family residential, office buildings, etc. Source: http://www.georgetownclimate.org/adaptation/toolkits/green-infrastructure-toolkit/regulatory-tools.html
Stormwater ordinances	Taking stormwater runoff management as an example, ordinances can be used to enforce the integration of GI into a stormwater runoff program, including: street standards, parking requirements, setbacks, open space or natural resource plans, comprehensive, watershed or facility master plans. For example, street standards should ensure that roads do not create excess impervious cover. Source: https://www.usgbc.org/articles/green-infrastructure-exploring-solutions-leed-sites-and-parksmart
Market Instruments/Incentives	
REDD+	At the current stage, NI solutions are receiving indirect support from existing policy frameworks under the umbrella of natural capital preservation or climate change mitigation by reducing emissions. Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) is an example of such a framework. The restoration and conservation of mangrove landscapes for mitigation purposes is eligible for financial support under the REDD+ strategies, policies and measures (Crooks et al., 2011). However, policy frameworks considering other NI typologies such as coastal wetlands and near-shore ecosystems still need to be developed or existing frameworks need to be altered (Crooks et al., 2011; Sutton-Grier, Wowk, & Bamford, 2015). Source: http://www.un-redd.org/
Payment for ecosystem services (IUCN, 2015; WBCSD, 2017)	Projects based on the beneficiary-pays principle: the beneficiary of an ecosystem service pays the provider of that ecosystem service. Source: http://ec.europa.eu/environment/life/funding/financial_instruments/ncff.html
Innovative financing models (WBCSD, 2017)	Market-based mechanisms such as the Washington, D.C. Stormwater Retention Credit (SRC) Trading Program allows landowners to generate SRCs for the implementation of GI for stormwater management and then to trade their SRCs so that others can meet the regulatory requirements for stormwater retention. The revenue stream generated from such programs creates an incentive to implement GI.

Policy	Definition
Financing	
Direct investment	Under financing initiatives such as the NCFF, banks such as the European Investment Bank can both directly and indirectly provide financing through loans and investments in funds to support projects related to NI and GI. Source: http://ec.europa.eu/environment/life/funding/financial_instruments/ncff.htm Financial institutions such as development banks, insurance companies, venture capital funds, commercial lenders and grant-making institutions can directly support NI projects. They can also help overcome the high transaction costs associated with NI projects by providing technical assistance and offering preferred lending or other incentives for investing in NI. For example, the Inter-American Development Bank offers technical assistance to clients that are willing to incorporate natural capital management into a broader project proposal (IUCN, 2015).
Incentivizing private sector investments	The private sector, particularly utilities, has an important role to play in investing in GI, but government policy must make an effort to reduce risk (European Commission, 2013). Proof of concept projects regarding cost savings, risk-adjusted profiles and revenue generation can help attract private investment for NI (WBCSD, 2017).
Public–private partnerships (PPP)	Another way to reduce risk is by supporting the development of multi-partner deals involving public and private funds (European Commission, 2013). PPPs are proving to be essential for funding of NI when the scale of the project is too large for one entity to fund it alone. For example, a PPP was necessary for the implementation of Europe's largest constructed wetlands in Italy for power plant cooling (WBCSD, 2017).
Tax incentives (WBCSD, 2017)	Tax benefits can be an important infrastructure incentive, particularly in North America and Europe. In Germany, tax incentives, fees and regulations for stormwater management on individual properties has led to Germany being the country with the highest number of green roofs in the world (Waterford, 2015).
Capacity Support and Awareness	
Building the business case for NI (WBCSD, 2017)	This entails: • Further development and elaboration on cost-benefit assessments for different infrastructure options, particularly combining them with life-cycle assessments studies that quantify environmental and social impacts (UNEP, 2014). This highlights the co-benefits and therefore competitiveness of NI versus grey infrastructure. • Environmental groups compiling case studies and disseminating research. These groups can help connect currently distant actors across sectors and organizations by providing the setting for peer-to-peer learning and for establishing relationships for the scaling-up of NI (IUCN, 2015). • Pilot testing is deemed an important method for quantifying the benefits of NI across different geographies and contexts, which helps overcome the barrier of uncertainty faced by investors (UNEP, 2014). • Testing the screening and spatial analysis tools to generate insights about the geographic areas and specific conditions where NI is viable (IUCN, 2015). • Publicly releasing the results of assessments and identifying the barriers to NI provides grounds for replication of such projects and for the development of the robust policy frameworks needed to encourage the implementation and financing of NI (IUCN, 2015). All of the above are important for scaling-up NI because they help make decision-makers aware of the technical feasibility and cost-effectiveness of NI. The stronger the business case for NI, the easier it will be to overcome biases against it, helping to legitimize this alternative to grey infrastructure (IUCN, 2015).
Promoting inter-agency coordination (IUCN, 2015)	The formation of multistakeholder partnerships is important for the scaling-up of NI projects. This will help reduce the high transaction costs associated with NI projects that have to work across several regulatory jurisdictions and with dispersed landowners.
Voluntary, user-driven watershed investments	This channels payments from water users, from companies or water utilities acting on the behalf of customers, to landholders or other "sellers" of ecosystem services, in exchange for the development of GI. Source: https://www.forest-trends.org/wp-content/uploads/imported/2016SOWIReport_ES.pdf

5.0 Actors Involved

5.1 Government

Ministries for the environment and infrastructure, public utility companies (e.g., fresh water and wastewater services) and international governance structures (e.g., EU) play an important role in NI implementation in terms of financing and developing the robust policy mechanisms required for the streamlining of NI.

Example

The Canadian government committed almost CAD 12 billion to public transit, NI and social infrastructure. Approximately half of the funding was directed toward water management, climate adaptation and capacity building (Infrastructure Canada, 2017).

5.2 Insurance Companies

Insurance companies play an important role in implementing NI projects either directly and/or by supporting partnerships related to NI, mostly to reduce risk (e.g., climate risk). Strategic partnerships between insurance companies and NGOs can be critical for advancing the business case for sustainability.

Example

Tokio Marine & Niched Fire Insurance Co., Ltd. has planted 8,994 hectares of mangrove forest in the Asia-Pacific region. Thanks to this initiative, the company has been carbon neutral in domestic operations since 2009.

Example

Swiss Re, in collaboration with The Nature Conservancy, has worked to demonstrate the cost-effectiveness of coastal ecosystems for risk reduction and climate adaptation. This has helped to support decision making regarding risk reduction and to design new finance mechanisms for NI projects (WBCSD, 2017).

5.3 Private Sector

There are several categories of involvement that the private sector has regarding NI. These include large infrastructure companies, agricultural firms, commodity traders, mining businesses and tourism. Utilities and companies who design and implement water, energy and food security projects are ultimately those that decide whether or not to incorporate NI into these projects. Some take steps to determine the viability of NI in their projects.

Example

Dow Chemical and Shell Oil have established teams responsible for reviewing potential NI implementation among the corporate infrastructure projects in the pipeline (Maxwell, McKinsey, and Traldi 2014, as cited in IUCN, 2015).

5.4 NGOs and Civil Society

NGOs can increase awareness and encourage funding for NI. These include wildlife protection organizations, multilateral agencies, foundations, etc. They do so primarily via their data-sharing services and connecting actors from different sectors and organizations. They may also actively work for the protection of NI.

Example

The Massachusetts Audubon Society, located in the United States, is a non-profit organization that dedicates itself to protecting and maintaining over 37,500 acres of land within the State of Massachusetts.

5.5 Individuals

Households can both be affected by NI and support their implementation. Urban gardening is an illustrative example. In North America, food products are known for their carbon footprint, as they travel an average of 2,000 km (Toronto Food Policy Council, 1999). A case study in Kingston found that food consumed locally can travel up to 4,685 km. If these food products were to be produced by local growers or urban gardeners, there would be a reduction of approximately 21,000 tonnes of annual GHG emissions for Kingston, the equivalent of taking over 6,700 cars off the roads (Lam, 2007).

Urban agriculture is an important example of how individuals contribute to the implementation of NI projects. Urban agriculture refers to the production of crop and livestock goods within cities and is often integrated into the urban economic and ecological systems (Mougeot, 2010; Zezza & Tasciotti, 2010). Examples include green roofs and green spaces, which have been explored earlier in this document. It is considered an essential feature of the overall urban support system and contributes to the sustainability and resilience of a city (Barthel & Isendahl, 2013).

As is inherent to NI assets, urban agriculture provides a wide range of co-benefits to the local community: local food production, places for recreation and social interaction, biodiversity preservation and carbon sequestration/storage. The potential of urban agriculture to deliver ecosystem services is due to its "spillover" of energy, resources and organisms across habitats. This spillover is vital to the survival of wildlife populations in urban contexts because it drives re-colonization and resource acquisition (Blitzer et al., 2012).

6.0 Data and Parameters for Nature-Based Infrastructure

Through the use of various mechanisms, such as ecosystem evaluation tools, the costs and benefits of NI can be measured based on financial, environmental and social outcomes of investment. Generally, decision-makers choose among strategies by evaluating their return on investment, either over some finite time horizon (e.g., 20 years) or using net present value (McDonald, 2015).

For instance, it has been found that a 10 per cent increase in forest cover near a watershed can decrease water treatment costs by 20 per cent (Ernst, Gullick, & Nixon, 2004; McDonald, 2015) and that the return on investment of the project is positive.

Below we identify and present the main methodologies and data inputs that are available and required to carry out a systemic cost-benefit analysis and project financing assessment of NI assets.

6.1 Tools for NI Investments

a) *Green Infrastructure North West (UK), Valuation Toolkit*. The tool takes various environmental, social and economic components into account when assessing specific projects or plans: natural resources needed, tourism, economic growth and investment, health and well-being, productivity, land and property values, quality of location, flood alleviation, climate adaptation and recreation.

Specific Case of Application: Stockport Town Centre Urban Green Infrastructure Enhancement Strategy

Natural infrastructure implementation provides an added value of well over GBP 100 million in benefits to the Stockport Town Centre. The additional proposed interventions could add upwards of GBP 60 million.

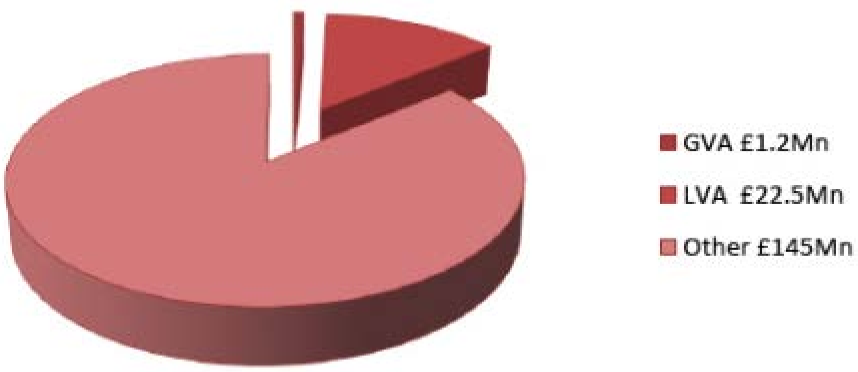

Figure 2. Existing GI valuation

Source: The Mersey Forest, n.d.

Table 12. The benefit monetization of Stockport Town Centre existing GI derived from the Green Infrastructure Valuation Toolkit

BENEFITS	BENEFIT MONETISATION		
Benefits groups	GVA value	Land and Property Value (LVA)	Other economic value
1 Climate Change Adaptation & Mitigation	£1,165	n.a.	£131,567
2 Water management & Flood Alleviation	£230,434	n.a.	n.a.
3 Place & communities	n.a.	n.a.	n.a.
4 Health & Well-being	n.a.	n.a.	£138,381,557
5 Land & Property Values	n.a.	£22,519,485	n.a.
6 Investment	n.a.	n.a.	n.a.
7 Labour Productivity	£347,021	n.a.	n.a.
8 Tourism	£0	n.a.	n.a.
9 Recreation & leisure	n.a.	n.a.	£589,941
10 Biodiversity	n.a.	n.a.	£6,614,528
11 Land management	£618,965	n.a.	n.a.
TOTAL ECONOMIC VALUE OF BENEFITS	£1,197,585	£22,519,485	£145,127,652

Source: The Mersey Forest, n.d.

b) The Environmental Protection Agency's Green Infrastructure Modelling Toolkit (EPA, 2018a)

The toolkit has several different means of valuing infrastructure implementation and projects. It comprises the following specific tools:

- The Watershed Management Optimization Support Tool (WMOST) looks at water management costs and impacts on the environment in relation to preexisting grey infrastructure.
- Green Infrastructure Wizard (GIWiz) assesses the value of natural landscapes in water management processes, allowing for a database for community or urban planners.
- The Visualizing Ecosystems for Land Management Assessment (VELMA) model was made to provide information on water quality, specifically removal of pollutants, and NI connections.
- The Green Infrastructure Flexible Model (GIFMod) analyzes stormwater runoff from urban and agricultural environments, while evaluating manners of management and filtration.
- The Storm Water Management Model (SWMM) is a simulation model used to contextualize urban runoff water quality issues and durable solutions.
- The National Stormwater Calculator (SWC) is a software application that is designed to calculate the impacts of annual rainfall within site-specific locations and the effects that may come from that, including water table rise or fall, drought, flooding, soil degradation, etc.

c) *Natural Capital Project: In-VEST: Integrated Valuation of Environmental Services and Tradeoffs, based on ArcGIS.*

d) *Centre for Neighbourhood Technology (2010): The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits.*

e) *Green Rails is "reducing the urban heat island effect by greening the rails of trams" (Best Climate Practices, n.d.).*

A general overview of NI components, their benefits and costs, and factors relevant for climate change is provided in Table 13.

6.2 Available Data for NI

A general overview of NI components, their benefits and costs, and factors relevant for climate change is provided in Table 13.

Table 13. NI and nature-based measures: Summary table on risk reduction performance, costs and factors relevant to climate change

Key - = Low confidence, feature not likely to address + = High confidence, data available ~ = Limited confidence refinement needed Blank = need data			Risk Reduction Performance					Design/O&M Criteria	Costs per linear foot		Other Factors	
			Reduce coastal erosion/ Shoreline Stabilization	Nuisance floods (high tides with sea level rise)	Short wave (<2') attenu-ation (Stabilize Sediment)	Reduce force & height of med. waves (2-5')	Storm Surge (low frequency extreme events)	(for performance areas specific to feature)	Construction	Annual O&M	Mitigates climate change (CO_2 sequest-ration)	Adaptability to sea level rise & changing community needs
Strategy	Structural	Groins	+	-	+			+	$2-5k	$.1-.5k	No	
		Breakwaters	+	-	+	+		+	$5-10k	>$.5k	No	Variable
		Seaawall/ Revetments/ Bulkheads	+	+		+	+	+	$5-10k $5-10k $2-5k	>$.5k $.1-.5k $.1-.5k	No	
		Surge Barriers	-			+	+	+	>$10k		No	
	Existing Natural	Wetlands	+		+	~	~	N/A	N/A		Yes	Yes
		Mangroves/ coastal forest	+		+	+	+	N/A	N/A		Yes	Yes
		Vegetated Dunes	+		+	+	+	N/A	N/A		~	Yes
	Nature-based	Beach Nourishment	+	+	+	+		+	$2k-5k	$.1k-.5k		Yes
		Vegetated Dune creation	+	+	+	+	+	+	$.03k- 5k	$.1k-.5k	~	Yes
		Barrier Island Restoration	+	+	+	+	+	+	$0.76k - $1.1k			Yes
		Small scale edging and sills (living shorelines)	+	~	+				$1k-2k	<$.1k	Variable	Yes
		Restored Oyster/Shell-fish Reefs	+		+	~	~	Possible, akin to low breakwaters	$.23k - .24k		Yes	Yes
		Restored/ Created Coral Reefs	+		+	~	~	Possible, akin to low breakwaters	$.2k – 508k		~	
		Restored Maritime Forests (including Mangroves)	+	+	+	+	+		$.23k - 216k /ha (mangroves)		Yes	Yes
		Restored Wetlands	+	+	+	~		-	$0.81k- 36.4k/ha		Yes	Yes

Source: Copyright © 2019 Environmental Defense Fund. Used by permission. The original material Cunniff & Schwartz, 2015.

6.2.1 Cost of Wetlands

Noack (2018) provides an overview of the capital costs for earthwork for establishing artificial wetlands. The development of costs for earthwork of artificial wetlands are depicted in Figure 3. The trendline indicates an exponential reduction in costs with the increasing size of water surface of the wetland.

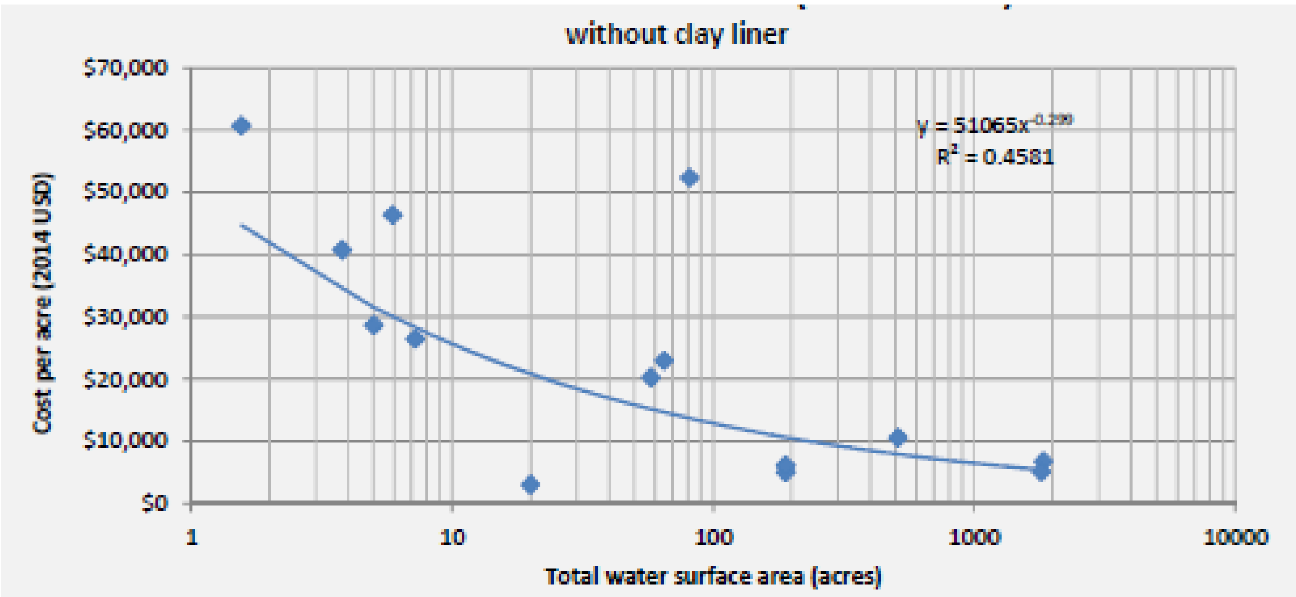

Figure 3. Earthwork cost per acre compared to the total water surface area of constructed wetland

Source: Noack, 2018.

Table 14 summarizes the different cost components for three FWS wetlands installed in Texas. Information about the total wetland size (acres) and capacity (million gallons per day, MGD) are provided for each of the projects, together with ratios of cost per area and cost per unit of capacity. The figures indicate that earthworks constitutes almost half (42 per cent) of the total cost for the installation of the wetland (Noack, 2018).

Table 14. Capital cost components of artificial wetlands

Operational parameters	Wetland 1		Wetland 2		Wetland 3	
Size (acres)	512		65		5.9	
Capacity (MGD)	31.9		2.9		0.2	
Cost components	**Cost (USD)**	**% of costs**	**Cost (USD)**	**% of costs**	**Cost (USD)**	**% of costs**
Site preparation	-	-	-	-	11,500	4%
Influent splitter box	-	-	137,000	8%	-	-
Water control structures	2,139,000	19%	41,500	2%	34,400	12%
Earthwork	4,685,000	42%	1,000,500	55%	104,500	36%
Aquatic plants/seedlings	1,218,000	11%	314,500	17%	50,000	17%
Roads	1,905,000	17%	-	-	-	-
Dewatering	600,000	5%	357,000	20%	-	-
GCs & demo	660,000	6%	60,500	3%	30,000	10%
Electrical / Instrumentation	-	-	40,000	2%	-	-
Re-lift pump-station	-	-	-	-	63,900	22%
Total	11,207,000	100%	1,814,000	100%	294,300	100%
Cost per acre	21,889		27,908		49,881	
Cost per MGD	351,317		625,517		1,471,500	

Source: Noack, 2018.

The U.S. EPA (2000) estimates the capital cost for a 0.1 MGD FWS wetland at USD 154,800, or USD 259,100 if a plastic membrane liner is used, and O&M cost at USD 6,000 per year, as summarized in Table 15.

Table 15. Capital and O&M cost for FWS wetlands

Item	Cost ($)*	
	Native Soil Liner	Plastic Membrane Liner
Land Cost	16,000	16,000
Site Investigation	3,600	3,600
Site Cleaning	6,600	6,600
Earthwork	33,000	33,000
Liner	0	66,000
Soil Planting Media	10,600	10,600
Plants	5,000	5,000
Planting	6,600	6,600
Inlets/Outlets	16,600	16,600
Subtotal	**98,000**	**164,000**
Engineering, legal, etc.	56,800	95,100
Total Capital Cost	**154,800**	**259,100**
O&M Costs ($/year)	6,000	6,000

** June 1999 costs, ENR CCI = 6039*
Source: EPA, 2000

Figure 4 shows the results of a regression analysis on cost depending on the size of FWS wetlands for a sample of 84 wetlands (Noack, 2018).

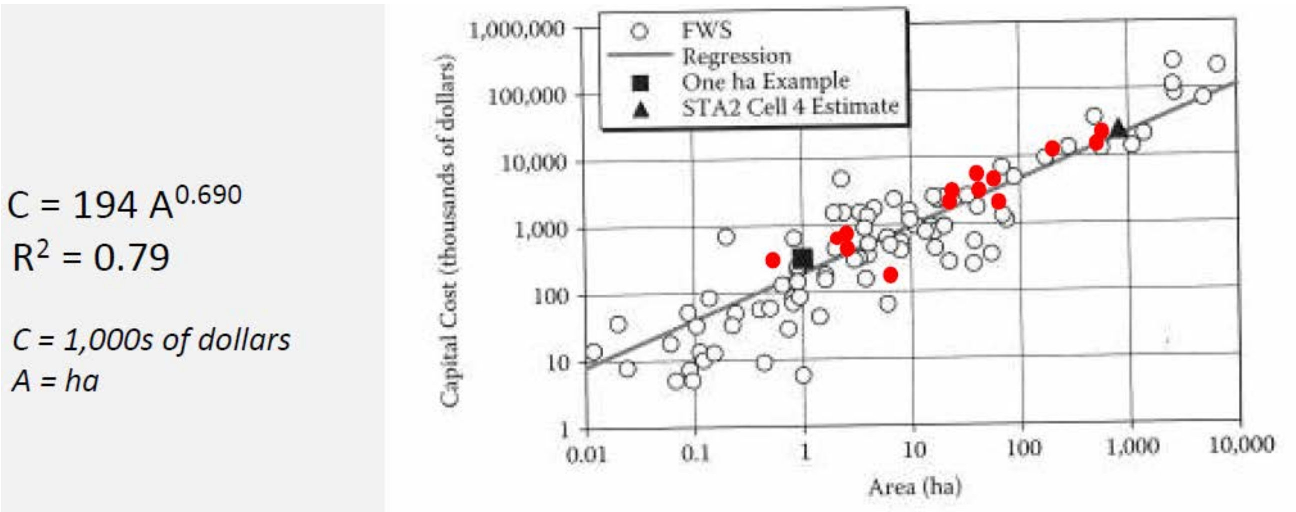

Figure 4. Regression analysis cost to area for artificial wetlands

Source: Noack, 2018.

According to the values provided by Noack (2018), O&M costs for artificial wetlands range between USD 1,400 and USD 4,000 acre/year. A financial assessment comparing a mechanical plant with an artificial wetland yielded net present value savings of USD 282 million for the wetland, assuming a 30-year project lifetime due to the combination of low capital and low O&M cost.

Table 16. Financial indicators sequencing batch reactor versus constructed wetland (1995 values)

Input	*Sequencing batch reactor*	*Constructed wetland*
Labor (FTE[a]/yr)	12	0.75
Electricity[b] (kilowatts/yr)	7,500,000	260,000
Maintenance (% DFC/yr)	1.9	0.9
Factory overhead cost (% DFC/yr)	1.9	0
Taxes and insurance (% DFC/yr)	1.2	1.2
Miscellaneous costs (USD/yr)	245,000	26,000
Direct fixed capital (million USD)	40	1.5

[a]Full-time equivalents ($100,000–$125,000/FTE)
[b]Assume average industrial electricity rates.
yr = year; DFC = direct fixed capital; USD = U.S. dollars.

Source: DiMuro, Guertin, Helling, Perkins, & Romer, 2014.

Table 17. Restoration costs for different NI components from specific cases

Restoration Effort and Context	Cost
Eelgrass restoration in harbour (seabed) following the installation of an oil pipeline	170,000 EUR/ha
Restoration of coral reefs (Southeast Asia, Florida Keys)	5 Mn – 80 Mn EUR/ha
Restoration of mangroves in West Lake estuary (Port Everglades, USA)	7,148 EUR/ha
Restoration mangroves in the Bolsa Chica estuary, California	325,000 EUR/ha
Restoration of freshwater wetlands in Denmark	8,375 EUR/ha
Control for phosphorous loads in stormwater treatment wetlands	25,000 EUR/ha
Restoration of the little Tennessee River, North Carolina	4,825 EUR/km (riparian buffer) – 11,870 EUR/km (restoration)
Restoration of the Skjern River, Denmark	130,000 EUR/ha
Restoration of the Cheonggyecheon River, Seoul	120,000 EUR/ha
Re-establishment of native eucalyptus trees in former grassy woodland, southeast Australia	285-970 EUR/ha
Restoring land to increase forage for bumblebees in intensively farmed landscapes in the U.K.	101 EUR/ha
Restoration in Coastal British Columbia Riparian Forests	2,200 EUR/ha
Masoala Corridors Restoration, Masoala National Park, Madagascar	11-670 EUR/ha
Restoration of rainforest corridors, Andasibe area, Toamasina Region, Madagascar [Tetik'asa Mampody Savoka TAMS]	570-1,250 EUR/ha
Polylepis forest restoration, Peru	760 EUR/ha
Restoration of oldfields, New South Wales, Australia	16,000 EUR/ha
Restoration of the Atlantic Forest (Mata Atlântica), Brazil	2,600 EUR/ha
Working for water, South Africa	200-700 EUR/ha
Mangrove restoration from former shrimp farms	8,00-9,300 EUR/ha

Source Adapted from TEEB, 2011.

Table 18 provides an overview of reported restoration costs and replacement cost ratios for natural breakwater infrastructure components (Narayan, et al., 2016).

Table 18. Restoration costs and coastal protection benefits of nature-based defence structures

Habitat	Reported Restoration Project Costs^ as US $ Per m^2: Median (Range)	Estimated Replacement Cost Ratios*: Average (*95% CI*)	% of Projects implemented for coastal protection	% of Projects in High Exposure Regions #	% of Projects reporting coastal protection benefits†
Coral Reefs (*n = 19*)	115.62 (2–7490)	NA	5	80	ER– 5; FL– 5
Oyster Reefs (*n = 4*)	135.63 (107–316)	NA	75	50	NA
Salt-Marshes (*n = 17*)	1.11 (0.01–33)	2 (0.95–3.01)	69	77	ER– 6; FL– 41; ST– 18; BC– 6
Mangroves (*n = 12*)	0.1 (0.05–6.43)	5 (3.1–6.9)	76	35	FL– 50; ST– 34; BC– 41

Source: Narayan, et al., 2016.

Figure 5 represents the wave height reduction effectiveness of nature-based defence (NBD) projects (top) and alternative breakwaters of NBDs (bottom) plotted based on costs and water depth. Cost curves of alternative breakwater structures plotted versus water depth are plotted for: a) mangroves (n=7) and breakwaters in Vietnam and b) salt marshes (n=6) and breakwaters in Europe/the United States. Circles represent NBDs and lines represent submerged breakwater cost curves in both panels. NBDs that fall below breakwater cost curves are cost-effective in comparison. Breakwater cost curves are for an incident wave height (Hsi) of 0.2 m. All costs are represented on a per-metre-of-coastline length basis. Figure 5 only shows mangroves and marshes as these were the only habitat types and locations for which project information was found in close proximity to field measurements (Narayan, et al., 2016).

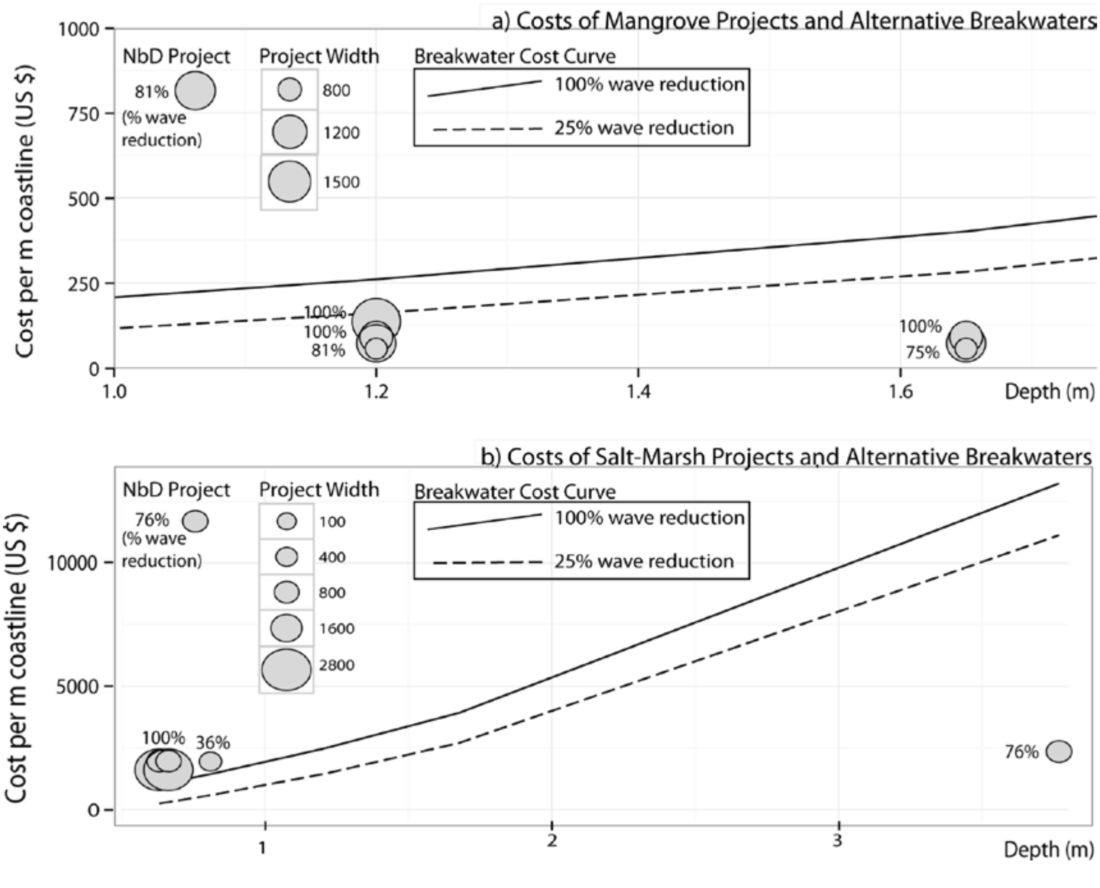

Figure 5. Costs versus water depth and wave height reduction extents of NBD projects and alternative breakwaters

Source: Narayan, et al., 2016.

The sustainable management of forests contributes to maintaining biodiversity and important ecosystem services. Table 19 provides an overview of potential sustainable forest management practices, indications on how they contribute to source water management and associated costs (WRI, 2013).

Table 19. Nitrogen and phosphorus retention per hectare of wetland

PRACTICE	REDUCE SEDIMENT	PROTECT AQUATIC HABITAT	PROTECT OTHER ECOSYSTEM BENEFITS	ASSOCIATED COSTS
Temporary bridges on skid trails	HIGH	HIGH	HIGH	LOW $4,500 or $75/harvest
Road and stream crossing monitoring, maintenance on annual basis, and periodic larger repairs for 15 years post-construction	HIGH	HIGH	HIGH	MODERATE $9,400/15yrs or $627/yr
Installation of culverts properly sized for projected flow conditions	HIGH	HIGH	HIGH	MODERATE to HIGH[a] 25–141 percent increase in materials cost
Harvest plan and on-the-ground planning and communications	HIGH	HIGH	HIGH	MODERATE $1,300/harvest
Low-impact riparian management zones[b]				
75ft, 40 percent timber volume removal	HIGH	MODERATE	MODERATE	MODERATE $231/acre of RMZ
75ft, no timber volume removal	HIGH	MODERATE	MODERATE	HIGH $584/acre of RMZ
150ft, 40 percent timber volume removal	HIGH	HIGH	HIGH	HIGH $692/acre of RMZ
150ft, no timber volume removal	HIGH	HIGH	HIGH	HIGH $1,152/acre of RMZ

[a] Cost category varies by width of culvert
[b] Cost estimates were adapted from LeDoux and Wilkerson (2006)

Source: WRI, 2013

6.2.2 Efficiency of Artificial Wetlands

A study conducted on 50 artificial wetlands in Sweden found that financial support from the government and the purpose of the wetland are important factors in determining the nutrient absorption from wetlands. Wetlands in Skåne County received government support and had nutrient absorption as the primary goal. Overall, the authors estimate that a reduction of 250 kg of nitrogen and 5 kg of phosphorous transported to the sea should be achievable for artificial wetlands (Jordbruksverket, 2010). Table 20 presents the results of the study as an average across all assessed wetlands and for specific regions.

Table 20. Nitrogen and phosphorus retention per hectare of wetland

Retention of N and P (kg / hectare /year)	Nitrogen (N) min	Nitrogen (N) max	Phosphorus (P) min	Phosphorus (P) max
All wetlands (n=50)	59	105	1.71	5.34
Wetlands with plant nutrient retention as the primary purpose (n = 16)	174	219	2.44	4.88
Wetlands in Skåne County with plant nutrient retention as primary purpose (n=6)	593	654	6.82	14.83

Sourcec: Jordbruksverket, 2010.

6.2.3 Benefits from Wetlands

Table 21 presents the cost per kilogram of nitrogen and kilogram of phosphorous removed based on O&M costs for wetlands and the respective nitrogen and phosphorous uptake of the wetlands. The standard O&M cost for wetlands in Sweden is SEK 3,000 per ha per year. The values are estimated based on a depreciation period/life span of 20 years for wetlands.

Table 21. Cost per kilogram of nitrogen and kilogram of phosphorous removed

Cost of N and P reduction (EUR* / kg)	Nitrogen (N) min	Nitrogen (N) max	Phosphorus (P) min	Phosphorus (P) max
All wetlands (n=50)	4.2	7.6	9.4	29.3
Wetlands in Södermanlands County (n = 5)	3.9	12.4	3.5	23.8
Wetlands in Skåne County (n=6)	3.4	3.8	16.6	36.1

**Exchange rate 8.45 SEK / EUR*
Source: Jordbruksverket, 2010.

The costs have been allocated to different ecosystem services depending on the stated purpose of the site of wetlands. The respective max refers to the minimum and maximum costs obtained depending on the different calculation models used for the calculation of the retention. Wetlands in Södermanland County represent relatively large wetlands with low plant cost per wetland area while wetlands in Skåne with plant nutrient retention primarily represent wetlands with high nitrogen loads (Jordbruksverket, 2010).

Table 22 represents the removal rate of GHG emissions from different types of wetlands

Table 22. GHG balance of coastal wetlands: soil burial of carbon dioxide and methane emissions

Wetland Type	Carbon Sequestration Potential		Methane Production Potential		Net Balance
	tC km^{-2} yr^{-1}	tCO$_2$e km^{-2} yr^{-1}	tCH$_4$ km^{-2} yr^{-1}	tCO$_2$e km^{-2} yr^{-1}	
Mudflat (saline)	Low (< 50)	Low (183)	Low (< 2)	Low (< 50)	Low
Salt Marsh	High (50–250)	High (183–917)	Low (< 2)	Low (< 50)	High
Freshwater Tidal Marsh	Very High (500–1,000)	Very High (1,833–3,667)	High-Very High (40–100+)	High-Very High (1,000–2,500+)	Unclear – neutral*
Estuarine Forest	High (100–250)	High (367–917)	Low (< 10)	Low (< 10, 250)	High
Mangroves	High (50–450)	High (184–917)	Low – High	Low – High	Depends on salinity
Sea grass	High (45–190),	High (165–697)	Low	(< 2, <50)	High

Note: 1gC ≡ 3.67 gCO$_2$e; 1gCH$_4$ ≡ 25 gCO$_2$e
* Too few studies to draw firm conclusions. Potentially CH$_4$ emissions from freshwater tidal wetlands may partially or fully negate carbon sequestration within soils.

Source: Crooks et al., 2011.

6.2.4 Economic Valuation of Nature-Based Infrastructure

In addition to flood protection, healthy mangrove forests provided a range of benefits. Table 23 provides an overview of the valuation of selected benefits obtainable from mangrove forests, based on a literature review conducted by Lewis III (2001). The majority of benefits stem from the fisheries sector, followed by sustainable forestry, fruits and thatches, and charcoal. The values are indicated in USD per hectare per year and in USD per hectare over a 50-year period.

Table 23. Valuation of selected mangrove benefits

Benefit	Value (USD$/ha/yr)	Value (USD$/ha/50 yr)	Source	Location
On-site sustainable fisheries	126	6,300	Ruitenbeek (1992)	Irian Jaya
On-site crustacean and mollusc harvests	126	6,300	Nielson (1998)	Vietnam
On-site sustainable harvest, all products	500*	12,500	Cabahug (1986)	Philippines
Fish products	538	26,900	de Leon and While	"
Vicinity fish harvests	1,071**	53,550**	Cabahug (1986)	"
Vicinity shrimp harvests	254**	12,700**	"	"
Vicinity mollusc harvests	675**	33,750**	"	"
Vicinity crab harvests	720**	36,000**	"	"
Off-site fisheries	189	9,500	Christensen (1982)	Asia
Off-site fisheries (managed)	147***	7,350***	Sathirathai (1998)	Thailand
Off-site fisheries (open)	92***	4,600***	Sathirathai (1998)	Thailand
Other products (e.g. fruits, thatch)	435	21,750	"	"
Sustainable forestry	756	37,800	Gammage (1994)	El Salvador
Charcoal	378***	18,900***	Sathirathai (1998)	Thailand
Biodiversity (capturable)	20	1,000	Ruitenbeek (1992)	Irian Jaya
Total direct use value	2,505****	125,250****	Sathirathai (1998)	Thailand
Waste assimilation	7,833	391,600	Lal (1990)	Fiji

* Page 453 in Cabahug (1986)
**Derived from Table 62-III in Cabahug (1986)(p. 455)
*** Assuming a conversion rate of 38 baht/ $USD 1
**** Mean value assuming a conversion rate as above

Source: Lewis III, 2001.

Table 24. Monetary values of services provided by wetlands (Int.$/ha/year – 2007 values)

Category of wetlands	Service category	No. of estimates	min value (Int.$/ha/y)	max value (Int.$/ha/y)
Coral reefs	provisioning services	33	6	20,892
	regulating services	17	8	33,640
	habitat services	8	0	56,137
	cultural services	43	0	1,084,809
	Total	**101**	**14**	**1,195,478**
Coastal systems (habitat complexes e.g. shallow seas, rocky shores & estuaries)	provisioning services	19	1	7,549
	regulating services	4	170	30,451
	habitat services	2	77	164
	cultural services	7	0	41,416
	Total	**32**	**248**	**79,580**
Mangroves & tidal marshes	provisioning services	35	44	8,289
	regulating services	26	1,914	135,361
	habitat services	38	27	68,795
	cultural services	13	10	2,904
	Total	**112**	**1,995**	**215,349**
Inland wetlands other than rivers and lakes (floodplains, swamps/ marshes and peatlands)	provisioning services	34	2	9,709
	regulating services	30	321	23,018
	habitat services	9	10	3,471
	cultural services	13	648	8,399
	Total	**86**	**981**	**44,597**
Rivers and lakes	provisioning services	5	1,169	5,776
	regulating services	2	305	4,978
	habitat services	0	0	0
	cultural services	5	305	2,733
	Total	**12**	**1,779**	**13,487**

Compiled sources in Russi et al., 2013: Brander, Florax, & Vermaat, 2006; de Groot, Stuip, Finlayson, & Davidson, 2006; TEEB, 2010; Ghermandi, van den Bergh, Brander, de Groot, & Nunes, 2010; Barbier, 2011; Brander, et al., 2011
Main source: Russi et al., 2013

6.2.5 Cost of GI Components

Table 25. Electricity requirements for different wastewater technologies based on capacity

Treatment Plant Size million gallons/day (cubic meters per day)	Unit Electricity Consumption kWh/million gallons (kWh/cubic meter)			
	Trickling Filter	Activated Sludge	Advanced Wastewater Treatment	Advanced Wastewater Treatment Nitrification
1 MM gal/day (3,785 m^3/d)	1,811 (0.479)	2,236 (0.591)	2,596 (0.686)	2,951 (0.780)
5 MM gal/day (18,925 m^3/d)	978 (0.258)	1,369 (0.362)	1,573 (0.416)	1,926 (0.509)
10 MM gal/day (37,850 m^3/d)	852 (0.225)	1,203 (0.318)	1,408 (0.372)	1,791 (0.473)
20 MM gal/day (75,700 m^3/d)	750 (0.198)	1,114 (0.294)	1,303 (0.344)	1,676 (0.443)
50 MM gal/day (189,250 m^3/d)	687 (0.182)	1,051 (0.278)	1,216 (0.321)	1,588 (0.423)
100 MM gal/day (378,500 m^3/d)	673 (0.177)	1,028 (0.272)	1,188 (0.314)	1,558 (0.412)

Source: Electric Power Research Institute, 2002.

6.2.6 Benefits from GI

Green Roofs

Table 26. Economic assumptions for the analysis of green roofs

		Value	Time Frame (Year)	NPV ($ m^{-2})
Economic Factor	Lifespan (year)	\	40	\
	Discount rate (%)	3	\	\
Individual Benefits ($ m^{-2})	Reduction of energy Use in heating and cooling	0.4–0.9	Annual	15.7–35
	Membrane longevity	160	At year 20	88.6
	Acoustic insulation	29	One time	29
	Aesthetic benefits	2.6–43.2	One time	2.6–43.2
	LEED certification bonus	n/a	n/a	n/a
Total NPV				135.9–195.8
Public Benefits ($ m^{-2})	Reduction in stormwater runoff	15 - 28	Annual	477.5–750.6
	Improvement of air quality	0.03	Annual	1.18
	Mitigation of urban heat island effect	n/a	n/a	n/a
	Increment of urban diversity	n/a	n/a	n/a
Total NPV				478.7–751.7
Lifecycle Costs ($ m^{-2})	Initial cost	15–540	One time	15–540
	Operation and maintenance cost	0.7–13.5	Annual	27.3–438.7
	Disposal cost	0.03–0.2	At year 40	0.01–0.06
Total NPV				42.3–978.8

Source: Feng, 2018

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