Foundation

# Foresight review of nature-positive engineering

## Building with nature in coastal and marine environments

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# About Lloyd's Register Foundation

## Our vision

Our vision is to be known worldwide as a leading supporter of engineering-related research, training and education, which makes a real difference in improving the safety of the critical infrastructure on which modern society relies. In support of this, we promote scientific excellence and act as a catalyst working with others to achieve maximum impact.

## Lloyd's Register Foundation charitable mission

- To secure for the benefit of the community high technical standards of design, manufacture, construction, maintenance, operation and performance for the purpose of enhancing the safety of life and property at sea, on land and in the air.
- The advancement of public education including within the transportation industries and any other engineering and technological disciplines.

## About the Lloyd's Register Foundation Report Series

The aim of this Report Series is to openly disseminate information about the work that is being supported by Lloyd's Register Foundation. It is hoped that these reports will provide insights for research, policy and business communities and inform wider debate in society about the engineering safety-related challenges being investigated by the Foundation.


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# Executive summary – Engineering a nature-positive future

Nature faces an unprecedented crisis. Biodiversity is declining at an unprecedented rate – faster than at any other time in human history – with average extinction rates estimated to be 100 to 1,000 times higher than those observed over the past tens of millions of years. We are now confronted with a triple planetary crisis encompassing climate change, biodiversity loss, and widespread pollution. These are not isolated challenges, but interconnected symptoms of unsustainable human activity. This is more than an environmental concern; it represents an existential threat with cascading economic and social consequences that affect every aspect of human civilisation.

Engineers now have both the opportunity and responsibility to serve as a key leverage point for nature recovery.

Engineers play a central role in shaping the built environment, ensuring it is safe, functional, fit for purpose, and meets the needs of society. Yet, we cannot ignore the significant role that the built environment has played in contributing to carbon emissions, habitat loss and resource depletion. Engineers now have both the opportunity and responsibility to serve as a key leverage point for nature recovery. Realising this potential requires systematic incorporation of nature-positive principles into their practice, ensuring that future development and the enhancement of nature go hand-in-hand to help meet global biodiversity and climate goals.

This foresight review explores the emerging field of Nature-Positive Engineering (NPE) through an in-depth exploration of three key sectors where engineering and natural systems interact significantly: coastal protection and adaptation; ports; and offshore renewable energy. The insights gathered aim to bring clarity, catalyse action within the engineering community, and support the safe, scaled adoption of NPE. Its findings and recommendations are designed to be relevant to all stakeholders involved in infrastructure development and transferable across all sectors.

NPE is a transformative approach that redefines the purpose and impact of engineering in our world. It involves actively protecting, restoring, and enhancing natural systems to deliver measurable ecological gains while simultaneously supporting societal wellbeing. NPE goes beyond sustainability's focus on 'doing less harm' to embrace a proactive model of 'doing more good,' positioning nature as a partner and ally in building resilient, thriving societies. It recognises nature as infrastructure in its own right, providing vital ecosystem services such as water purification, climate regulation, and coastal protection. NPE is a key pathway for implementing nature-positive infrastructure.

NPE requires embedding ecological principles throughout the entire infrastructure lifecycle – from concept and planning to implementation, operation, and decommissioning. By making nature gains a central design objective – alongside safety, efficiency, and functionality – engineers can demonstrate that infrastructure development and nature recovery can be mutually reinforcing, building environments that are both nature- and people-positive.

The review identifies ten guiding principles to support NPE implementation:

1. Foster a mutually enhancing Human-Nature relationship
2. Take a whole lifecycle approach to ecological impacts
3. Deliver measurable nature improvements
4. Recognise interconnectedness across scales and timeframes
5. Co-develop solutions with communities and Indigenous Peoples
6. Design multifunctional, regenerative systems
7. Manage complex risks and trade-offs
8. Address the climate-nature-health nexus through adaptive management
9. Foster interdisciplinary collaboration
10. Anticipate and manage potential unintended consequences

Innovative solutions aligned with NPE principles are already being implemented across the key sectors examined in this review, with coastal protection and adaptation demonstrating the greatest maturity. These examples demonstrate that implementation of NPE can lead to multiple benefits, from enhanced biodiversity and ecological resilience to improved community protection, human wellbeing, and economic opportunity. Central to future solutions is harnessing technology to scale up, and addressing the complex climate-nature-health nexus, with a better understanding and management of associated risks and trade-offs.

However, significant barriers persist, including fragmented policy, undervaluation of nature, limited financing, outdated technical standards, and a workforce in need of upskilling to address interdisciplinary challenges. Scaling NPE demands systemic transformation and coordinated action among stakeholders, focusing on the following key enablers:

- Policy frameworks that mandate biodiversity enhancement
- Financial mechanisms that recognise nature's true value
- Market incentives creating commercial attractiveness
- Educational approaches bridging engineering, ecology, and social sciences
- Upskilling current and future engineering workforces
- Research building a strong evidence base for practice
- Technical standards and guidance specific to nature-positive approaches
- Advocacy and partnerships to scale impact across sectors

Robust measurement, standardised frameworks, and long-term monitoring are essential for establishing NPE practices and scaling their implementation, incentivising investment, and demonstrating progress towards sustainable, resilient futures. Success will depend on interdisciplinary collaboration – bringing together engineers, ecologists, social scientists, economists, and local communities to co-design effective, equitable, and future-proof solutions. Industry and academia will play crucial roles in embedding nature-positivity into engineering practice and education.

To accelerate NPE, this review offers recommendations across three areas:

1. Create an enabling environment, including policies that leverage technology for integrated planning, embed biodiversity outcomes in permitting and procurement, and align finance with natural capital risk frameworks.
2. Building technical capacity through guidance to implement NPE across the lifecycle, a toolkit to design for interconnected climate-nature-health risks, standardised biodiversity metrics, case study research, and integrating NPE into education and professional development.
3. Advocacy and partnerships, establishing a global engineering NPE alliance and community of practice for knowledge sharing and policy influence, alongside targeted communications to policymakers, investors, and communities showcasing examples of successful NPE implementation.

Engineers must now find their voice in the global nature-positive movement. Each year of delay increases both the cost of action and the risk of irreversible damage to the complex living systems that support human health and safety, and deliver ecosystem services. The science is clear: restoring nature is one of our most powerful tools for creating a sustainable and resilient future. By embracing NPE principles, engineers can reshape human development to place nature and society at the heart of design, moving beyond harm minimisation towards recovery within planetary boundaries,[1] and fostering a more inclusive, equitable, and safer world where people and nature thrive together.

# Foreword

'As a species, we are expert problem solvers. But we haven't yet applied ourselves to this problem with the focus it requires.'
Sir David Attenborough

Engineering has long been one of the defining forces of human progress. From aqueducts and bridges to energy networks and digital infrastructure, engineers have translated vision into reality, creating the foundations of modern societies and enabling improvements in health, prosperity, and connectivity.

Yet this legacy is also marked by an unintended paradox. The infrastructure that has enabled human development has simultaneously contributed to ecological degradation, biodiversity loss, and climate instability. The prevailing assumption that nature could be controlled, simplified, or replaced has too often led to the depletion of the very systems on which life depends.

Today, the climate crisis, biodiversity decline, and pervasive pollution are no longer separate challenges but interconnected symptoms of systemic imbalance between human and natural systems. [2] Addressing them requires a profound shift in how engineering and the societal systems in which it operates are conceived and practiced. Rather than treating nature as an external constraint, we must recognise it as a partner in resilience, adaptation, and regeneration.

For the engineering profession, this represents a redefinition of purpose. The challenge is not only to minimise harm but to actively design infrastructure and technologies that restore ecological health while meeting human needs. This will require new approaches to standards, education, and practice – embedding ecological literacy and systems thinking alongside technical excellence.

Such a transformation will not be straightforward. It entails navigating institutional inertia, rethinking established methods, and building capacity across professions and disciplines. But it also presents an extraordinary opportunity: to shape a future in which infrastructure contributes to thriving ecosystems as well as thriving societies.

Engineering has always been about solving complex problems. The task now is to harness that ingenuity to ensure that human systems and natural systems are no longer in conflict, but in alignment, building the conditions for long-term resilience and prosperity.

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# Background

This foresight review is the latest in a series commissioned by Lloyd's Register Foundation. These reviews aim to identify future trends, explain them in simple terms, understand their impact on the engineered world, describe opportunities and threats that arise from them, and identify what is needed to scale safely and realise the societal benefits.

This foresight review examines the emerging field of **Nature-Positive Engineering (NPE)** which was identified within a recommendation of the foresight review of ocean engineering.

This review aims to clarify what 'nature positive' means when applied to the engineering domain. We explore how NPE approaches are currently implemented, and identify challenges, opportunities and emerging trends, and provide a framework for engineering approaches to protect, restore and enhance natural ecosystems.

The review conducts an in-depth exploration of three key sectors where engineering and natural systems interact significantly: **coastal protection and adaptation; ports and offshore renewable energy (ORE).** These sectors were selected because they play crucial roles in building climate resilience, supporting decarbonisation efforts, and protecting marine environments – some of our planet's most vulnerable and valuable ecosystems.

The findings of the review draw from extensive global engagement efforts, including:

- five roundtables that brought together over 200 key stakeholders from 30 countries across four continents
- one-on-one interviews and focus groups with 30 subject matter experts
- an open global call for input, and
- a comprehensive examination of published literature, case studies, and existing resources.

The engagement process incorporated diverse perspectives from across the engineering profession, government agencies, academic institutions, civil society organisations, energy companies, port operators, and financiers.

The findings and recommendations of the review are intended to bring clarity, catalyse action from the engineering community, and **support and accelerate the safe adoption of NPE at scale.**

# The social, environmental and economic imperative for change

**Nature is our most precious asset. Without nature, there is no society.**

Within natural systems, the ocean plays a particularly critical role. Covering 71% of Earth's surface and home to roughly 80% of all life, the ocean is central to climate regulation and biodiversity. The global ocean economy, currently valued at over $2 trillion and having doubled in the last three decades, supports millions of jobs and underpins the livelihoods of hundreds of millions of people.[3]

### What is biodiversity and why is it important?

Biodiversity is the variety of all living species within an ecosystem that underpin its stability, productivity, and resilience. Healthy ecosystems, rich in biodiversity, perform essential functions such as nutrient cycling and photosynthesis, and provide critical services including climate regulation, water purification, a source of food, and clean air. When biodiversity declines, ecosystems weaken and their ability to deliver these services diminishes. Human-driven pressures like climate change, pollution, and overexploitation are major drivers of biodiversity loss. Because biodiversity is a key indicator of ecosystem health, its decline is widely used in science and policy to signal broader nature loss.[4]

**We have collectively failed to engage with nature and ocean systems sustainably[5].** Biodiversity is declining faster than at any time in human history, with average extinction rates 100-1,000 times[6] higher than the past tens of millions of years. Perhaps because the oceans appear vast, powerful, and unchanging, there has been a false sense of resilience, leading to widespread neglect and overexploitation.

**Climate, biodiversity, and water, food, and health systems are deeply interconnected – changes in one area can trigger cascading effects across the others.** Ocean systems provide a compelling illustration of these interconnections. Rising temperatures and increased $CO_2$ absorption create more acidic, oxygen-poor seawater, whilst sea level rise threatens both marine ecosystems and coastal human communities. These climate-driven changes reduce marine habitat areas, diminish biodiversity, and disrupt ecosystem functioning. The resulting environmental degradation creates cascading socioeconomic impacts across food security, fisheries, local cultures, and recreation. Indigenous peoples and coastal communities face particularly severe consequences, as these populations depend directly on marine resources for their health, wellbeing, and livelihoods.

**Nature's continued decline represents an existential threat to human wellbeing and economic prosperity.** Planetary boundaries, the thresholds that define the safe limits of Earth's critical systems[7] such as climate change and ocean acidification, are being exceeded with many ecosystems at imminent risk of irreversible tipping points[a,8] with catastrophic consequences for economies and societal wellbeing.[9] Low and middle income countries face the greatest vulnerability due to their greater reliance on local natural resources, highlighting the social injustice dimensions of ecological breakdown.[10] $44 trillion (over 50% of global GDP) is moderately or highly dependent on the ecosystem services that nature provides. A collapse of ecosystem services would cost 2.3 percent of global GDP ($2.7 trillion, about the size of the entire GDP of France) with some of the low and middle income countries hit hardest.[11] Delaying action to halt and reverse biodiversity loss by ten years is estimated to be twice as expensive as taking immediate action.[12]

**Halting and reversing biodiversity loss is not just an environmental imperative but a critical financial strategy that can unlock tremendous economic potential.** Analysis suggests that transitioning to a nature-positive economy could generate $10.1 trillion in business opportunities and create nearly 395 million jobs by 2030.[13] We need fast action from all businesses, governments and financiers if we are to realise positive change and avoid losing trillions over the next 15 years due to nature's decline.[14]

### The Kunming-Montreal Global Biodiversity Framework

The adoption of the Kunming-Montreal Global Biodiversity Framework (GBF)[15] at COP15 in 2022 marked a defining moment for action on biodiversity loss. This international agreement set out a global strategy to halt and reverse biodiversity loss by 2030, with the overarching vision of 'living in harmony with nature' by 2050. It acknowledges that conservation and restoration must also happen within engineered environments and be compatible with human development.

a A tipping point occurs when gradual small changes lead to a bigger, often permanent change, for example: rising temperatures can lead to ice melting resulting in rising global sea levels.

Building on the foundation of the Kunming-Montreal Global Biodiversity Framework (GBF)[16], the *'Nature Positive'* movement has gained significant momentum. It has become the global societal goal for nature recovery, requiring action to 'Halt and Reverse Nature Loss by 2030 on a 2020 baseline and achieve full recovery by 2050'.[17] However, a critical challenge emerges. Whilst many government agencies, businesses, and nonprofit organisations have embraced this concept, the term 'Nature Positive' is sometimes used too loosely and applied to actions that seem helpful but may not create the expected improvements. To maintain credibility and impact, the 'Nature Positive' approach requires clear rules, such as setting baselines and tracking actual outcomes, ensuring it reflects true gains for nature rather than merely good intentions.[18,19,]

**'Bending the curve'[20] refers to reversing that downward trend of biodiversity loss.**

Bold, transformative action is needed to halt and reverse harm to nature, and help its recovery. Only through integrated, systemic approaches can we 'bend the curve' so that biodiversity is visibly and measurably on a path to recovery. Key areas of action include (Figure 1): enhanced conservation and restoration of ecosystems; climate change mitigation; addressing pollution, invasive species, and overexploitation; creating more sustainable production systems for goods and services (especially food); and reducing overall consumption and waste.[21]

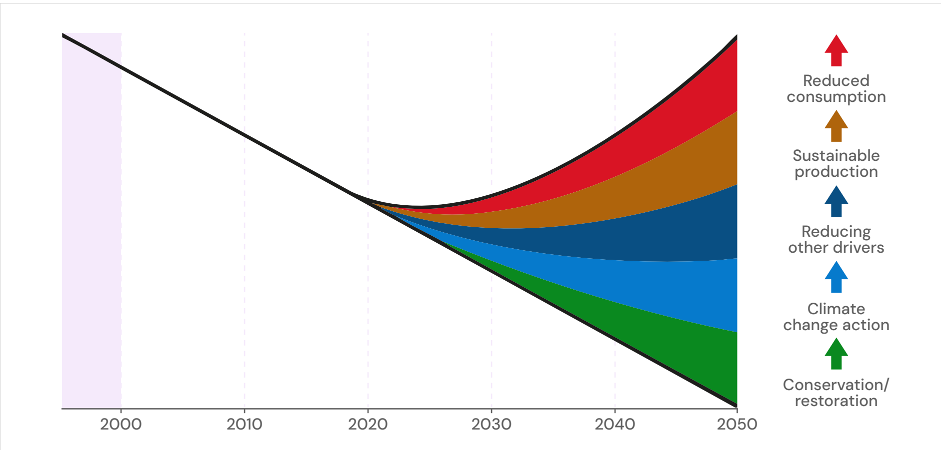



Figure 1 – Biodiversity degradation curves and aligned actions for protecting and restoring life on Earth. Source: CBD 2020a, GBO-5 SPM[22]

Crucially, no single action is sufficient – all drivers of biodiversity loss must be addressed simultaneously. These approaches work best when combined because they strengthen and complement each other.[23] The imperative for decarbonisation becomes significantly more urgent when viewed through the lens of interconnected climate and nature crises. Scientific consensus confirms that immediate cessation of new fossil fuel infrastructure development[24] and rapid transition to renewable energy[25] represent the most effective strategies for halting natural and ocean systems' deterioration.

This challenge becomes particularly acute when examining the built environment. Infrastructure is a major contributor to climate change, linked with up to 79% of carbon emissions globally.[26] Infrastructure also causes ecological damage[27] by taking up space from various native species without consideration of mitigation, restoration, or coexistence with nature.

**Seventy-five per cent of the infrastructure that will exist by 2050 has yet to be built.**[28] The opportunity to ensure that future infrastructure is low-emission, resource-efficient, resilient, and nature-positive is unprecedented. The rapid expansion of offshore renewable energy (ORE) is an example of the scale and pace of future development needed with offshore wind capacity expected to grow more than six-fold in 2030 and almost ten-fold in 2050 as compared to the capacity in 2018.[29]

**Engineers and other built environment professionals have a critical role to play**. As primary implementers and stewards of the built environment, they shape our world in ways that carry long-lasting ecological consequences. Engineers are a key leverage point for nature recovery. Realising this potential requires the systematic integration of nature-positive principles across all stages of infrastructure development to help meet global biodiversity and climate goals.

Harnessing growing societal momentum, engineers can reimagine infrastructure as a powerful catalyst for ecological recovery and enhancement.

# What is nature-positive engineering

Modern development has historically prioritised human advancement at the expense of the environment; 75% of the land-based environment and about 66% of the marine environment have been significantly altered by human actions.[30] Infrastructure projects often alter landforms, disrupt hydrology, and fragment ecological connectivity, triggering cascading effects on ecosystems and communities.

**Nature-Positive engineering (NPE)** refers to engineering practices that protect, restore, and enhance natural systems, delivering measurable gains for nature alongside societal wellbeing and need.

NPE challenges this paradigm by reframing nature as a critical ally and integral part of achieving human and planetary wellbeing. It is a systems-based practice that aims to deliver measurable gains for nature – protecting and restoring habitats, enhancing biodiversity, and strengthening ecosystem services. This approach recognises nature as infrastructure in its own right that provides essential functions such as water filtration, climate regulation, and coastal protection. Embedding nature positivity as a core engineering design objective, alongside safety, efficiency, and functionality, is key to 'bending the curve' of biodiversity loss.

While sustainability[31] has long been part of the engineering discourse,[32] a shift is needed from simply minimising environmental harm ('doing less harm') towards proactively protecting, restoring and enhancing ecosystems ('doing more good'). NPE supports this evolution by promoting a deeper, more intentional integration of engineering expertise with ecological principles in decision-making.

NPE charts a path toward restoration and regeneration (see Figure 2). Every improvement matters, at every stage. Restoration and regeneration are not possible without first reducing harm, so sustainable practices that minimise or avoid environmental damage remain essential. But harm reduction alone is no longer sufficient. The urgency of the nature crisis requires all future engineering interventions to aspire to deliver measurable ecological gains. Responsibility for this transformation cannot rest with engineers alone; it requires a systemic shift in policies, regulatory frameworks, design standards, performance metrics, and risk assessments to align development with the needs of both people and the planet.[33]

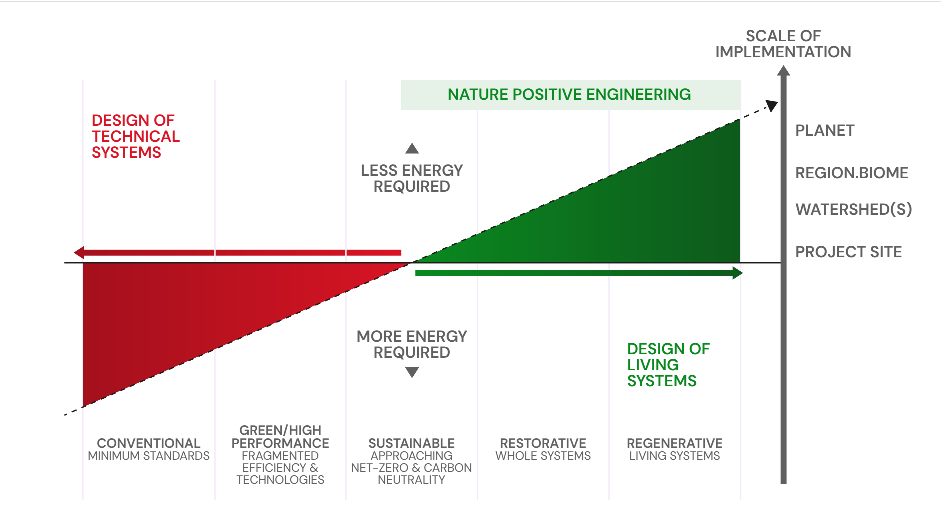



Figure 2 – NPE moving beyond sustainability. Adapted from (Mang & Reed, 2020)

We are not starting from scratch. A range of related concepts, approaches, and solutions already exist, and these should be integrated into the NPE implementation toolkit and leveraged to accelerate uptake. Rather than adding to an already crowded space, NPE seeks to unify and clarify, offering a universal framework and guiding principles applicable across all engineering contexts. It builds on and aligns with existing concepts, and is the engineering approach to implementing Nature-Positive Infrastructure[b], see Figure 3 below.

b A nature-positive approach that puts nature and biodiversity gain at the heart of decision making and design. It goes beyond reducing and mitigating negative impacts on nature as it is a proactive and restorative approach focused on conservation, regeneration and growth.

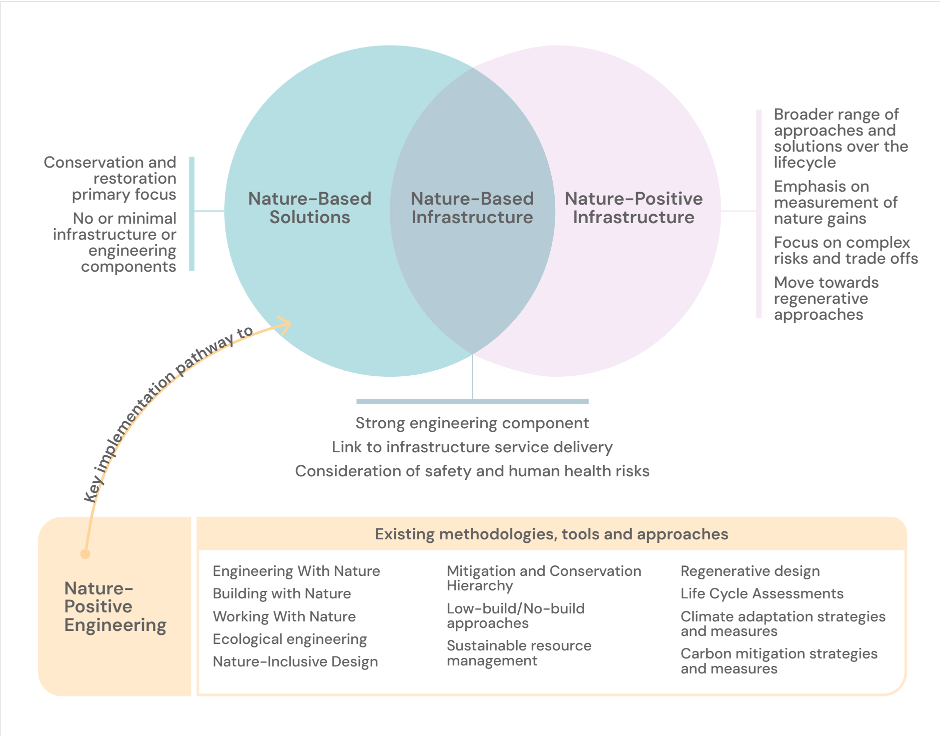



Figure 3 – Relationship of NPE with existing concepts and approaches. Refer to glossary in Annex 2 for definitions

Implementing NPE requires addressing all drivers of biodiversity loss and aligning multiple disciplines and approaches, such as environmental engineering, ecological design, circular economy, and climate mitigation and adaptation, around shared nature-positive goals. This demands interdisciplinary collaboration, bringing together engineers, ecologists, social scientists, economists, and other specialists, while fostering co-design with project developers, businesses, and local communities.

## Embedding NPE across in the lifecycle

**Nature-positivity should be a core principle in engineering decisions across the entire project lifecycle and value chain.** This means identifying opportunities at every stage – planning and design to construction, operation, and decommissioning – to prioritise nature alongside societal and financial objectives. It encourages the use of a spectrum of context-specific strategies, approaches and solutions, including nature-based and hybrid solutions, aligned with performance requirements.

| PLANNING | DELIVERY | MANAGEMENT |
|---|---|---|
| • Involve engineers early in Environmental Impact Assessments (EIAs) to integrate technical insight into decision-making.<br>• Set clear ecological and social baselines to track change and measure long-term impacts.<br>• Prioritise low-build or no-build options to avoid unnecessary ecological disruption.<br>• Integrate biodiversity and ecosystem services valuation into cost–benefit analyses to capture full natural capital value.<br>• Engage stakeholders early and often, integrating Indigenous and local knowledge to co-create transparent, equitable plans that fairly distribute benefits and risks.<br>• Apply tools like the mitigation hierarchy or natural capital assessments to guide planning and investment.<br>• Consider cumulative impacts of multiple projects on connected ecosystems.<br>• Account for future climate risks and their impacts on infrastructure, ecosystems, services, and communities. | • Understand natural systems and establish an ecological baseline at project site.<br>• Prioritise solutions that harness natural processes to deliver multiple functions, services, and co-benefits.<br>• Co-create solutions with local communities and decision-makers.<br>• Adopt regenerative design practices that are circular, adaptive, and context-specific.<br>• Use Life Cycle Assessments and Value Chain Analysis to select renewable, low-impact, or locally sourced materials.<br>• Embed nature-positive requirements into procurement through clauses and Key Performance Indicators (KPIs) Is linked to supplier sustainability performance.<br>• Plan and allocate budget for ecological monitoring throughout the asset's operational life.<br>• Treat decommissioning as a transition, planning for disassembly, reuse, and ecological restoration from the design stage. | • Operate and maintain infrastructure to minimise ecological disruption, improve efficiency, and optimise resource use.<br>• Implement a monitoring regime to measure ecological outcomes, generate evidence of long-term performance of solutions, and adjust interventions as new information emerges.<br>• Share monitoring data with regulators, stakeholders, and communities to build transparency and trust.<br>• Set ecological and resilience performance targets in operational budgets and KPIs.<br>• Integrate predictive maintenance and smart technologies to prevent failures and reduce environmental harm.<br>• Embed circularity and zero-waste goals across operations, including material flows and waste management.<br>• Build local capacity for long-term stewardship through training and community engagement. |

Figure 4 – Examples of actions that support implementation of NPE across the infrastructure lifecycle. Refer to glossary in Annex 2 for definitions

# Understanding nature-positive engineering through sector examples

The current and emerging practices described in the following sections demonstrate how NPE solutions are being implemented across key marine infrastructure sectors including coastal protection and adaptation, offshore renewable energy (ORE) and ports.

## Coastal protection and adaptation

Coastal infrastructure is shifting from purely engineered systems toward more integrated, resilient, and ecologically sensitive designs, though progress remains uneven and highly context dependent.[34] In response to the widespread degradation of coastal ecosystems, many countries are now exploring ways to reintroduce natural elements into artificial coastal and estuarine structures.

Understanding the natural system is the first step and the critical foundation for designing effective nature-positive interventions. In coastal areas, this process involves identifying key natural drivers (e.g., waves, currents), pressures (e.g., erosion, pollution), and natural responses (e.g., sedimentation, vegetation growth), as well as socio-economic interactions within the seascape. Nature-based and natural infrastructure strategies span a continuum from fully engineered to fully natural, with hybrid or green-grey solutions that integrate[35] both elements, often providing the most effective and reliable protection – especially in areas where safeguarding coastal properties, infrastructure, and communities is critical.

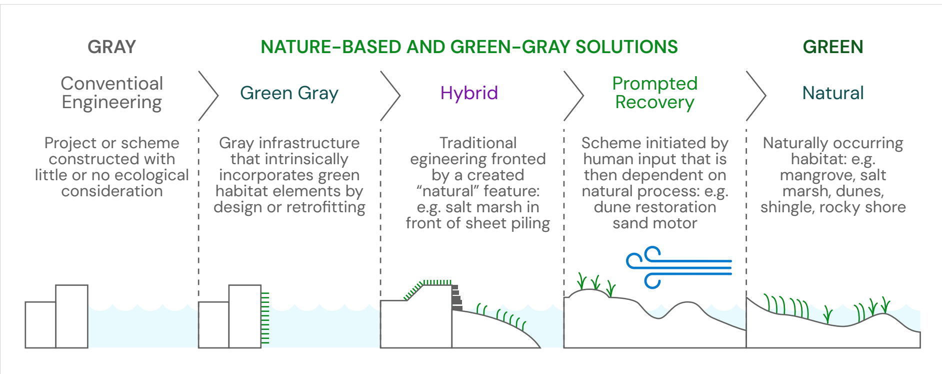



Figure 4a – Continuum of Nature-based techniques from simple additions to existing infrastructure to more elaborate schemes incorporating a suite of nature-based elements. After Naylor et al. (2017) and Sutton-Grier et al. (2015)

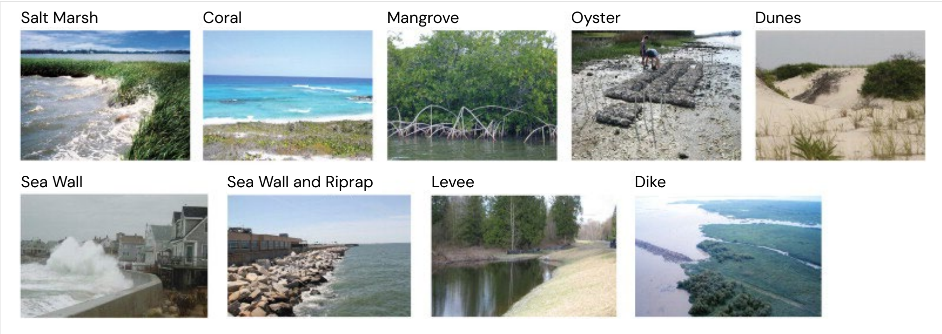



Figure. 4b. Examples of natural (top row) and built (bottom row) infrastructure. Photo Credits: NOAA for all images except Dunes (credit: American Green), Sea Wall (credit: University of Hawaii Sea Grant), and Levee (credit: J. Lehto, NOAA)

In addition to reducing erosion, storm surge, and flooding, these solutions create marine habitats and provide vital ecosystem services, such as natural carbon capture and storage, improved water quality, support for local livelihoods, and cultural benefits. Many of these approaches fall under ecosystem-based adaptation (EBA),[c,36] which uses ecosystem management to enhance resilience and reduce vulnerability for both people and nature in the face of climate change. Their flexibility, cost-effectiveness, and low maintenance make them powerful tools for implementing NPE. Among the areas covered in this foresight review, coastal protection is one of the most mature, offering valuable insights into what works. Examples[37] include:

- **Natural infrastructure solutions** such as mangrove forests, salt marshes, coral reefs, seagrass and dune systems offer natural buffers that reduce wave energy and erosion,[38] while sequestering carbon and supporting marine life.
- **Living shorelines** use materials like native vegetation, sand, and strategically placed rock to stabilise coastlines.
- **Sediment management interventions** use dredged or imported material to rebuild eroded wetlands or beaches.

c The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change.

- **Managed realignment projects** intentionally breach coastal defences to create intertidal habitats that absorb storm surges while supporting biodiversity.
- **Hybrid (green-grey) coastal protection solutions** combine engineered elements, such as seawalls or breakwaters, with natural features like mangroves or oyster reefs. These approaches provide reliable structural protection while reducing wave energy, enhancing biodiversity, and typically requiring less maintenance than traditional infrastructure while delivering multiple ecosystem benefits.

### Oro Loma Horizontal Levee – California, USA[39]

The Oro Loma Horizontal Levee in San Lorenzo, California, represents a pioneering NPE approach that addresses wastewater treatment while providing benefits in the areas of flood risk, water quality, and habitat enhancement. Constructed between 2015-2017, this 1.4-acre experimental facility demonstrates how infrastructure can be reimagined as living systems that provide multiple environmental benefits.

The Horizontal Levee project, Oro Loma, California, USA (Source: Link)

The horizontal levee features a 30:1 slope covered with native vegetation and engineered substrate layers that enhance wastewater treatment processes and nutrient removal and buffer tidal surges and rising sea levels, reducing flood risk and shoreline erosion. The system comprises twelve hydraulically isolated treatment cells with a layered structure composed of gravel, sand, loam, and woodchips, which optimises water flow and supports native plant and microbial communities, which are essential for effective contaminant removal.

The system has achieved remarkable performance outcomes, including greater than 98% nitrogen removal from treated wastewater and effective removal of pharmaceuticals, phosphate, and viruses, enhancing both water quality and ecosystem health. By establishing over 68,000 native plants, the levee provides critical habitat for wildlife and increases biodiversity.

Case study

**Building with Nature, Indonesia**[40]

Northern Java's deltaic coastlines face significant challenges from land subsidence, severe erosion, and frequent flooding. The removal of mangrove belts, unsustainable aquaculture practices, groundwater extraction, and poorly planned coastal infrastructure have exacerbated the region's vulnerability. Traditional hard infrastructure, such as dams and seawalls, has proven ineffective and unsustainable in addressing the complex challenges of muddy coastlines.

The Building with Nature approach in Northern Java combines NbS with hard-engineering techniques to address coastal erosion's root causes and enhance resilience. Mangrove restoration, provides a natural buffer against erosion, storm surges, and saline intrusion. Semi-permeable barriers made from local materials like brushwood and bamboo were constructed offshore to reduce wave energy, trap sediment, and create conditions conducive to natural mangrove regeneration. The restored ecosystems provide critical coastal protection while supporting biodiversity and improving ecosystem health. Mangroves serve as nurseries for various fish species, enhance carbon storage, and improve water purification. The reintroduction of mangrove belts has also revived local fisheries and created habitats for diverse marine and terrestrial species.

Permeable structures with natural mangrove regrowth, Demak, Indonesia (Source: Link, Photo by: Witteveen+Bos)

## Offshore Renewable Energy

Offshore Renewable Energy (ORE) encompasses wind, tidal, and wave technologies expanding rapidly to meet decarbonisation targets. By displacing fossil fuel emissions, ORE simultaneously addresses climate change and supports biodiversity recovery by reducing a key driver of nature's decline.[41] Offshore wind dominates current deployments globally.

In the most advanced regions, offshore wind projects increasingly integrate nature enhancement features, leveraging established regulatory frameworks, mature environmental assessment practices, and deeper industry experience with stakeholder engagement. There's growing momentum to ensure nature-positive engineering is embraced across the lifecycle, with several pilots and studies investigating coexistence between engineered structures and marine biodiversity.[42] However, uncertainty over environmental effects during construction and operation remains a major barrier to the consenting and timely deployment of offshore wind projects, increasing costs and adding pressure on regulatory systems.

Current and emerging nature-positive engineering practices across the lifecycle of offshore wind projects include[43,44,45]:

- **Offshore wind farm spatial planning** ensures turbines are located to avoid sensitive habitats and migration routes. Where impacts are unavoidable, restoration interventions such as seagrass replanting or oyster bed restoration, can potentially offset biodiversity losses.
- **Low-impact design measures** include silent piling technologies (e.g. suction caissons) or noise-reducing technologies during impact pile driving, to minimise disturbance to marine or freshwater ecosystems.
- **Ecological compensation measures** such as kittiwake hotels[46] are offshore artificial nesting structures designed to compensate for habitat loss linked to wind farm development.

- **Nature-inclusive designs (NID)**[d], a term used in the context of ORE, such as:
    - **Scour and cable protection measures** including specially designed concrete mattresses, biodegradable reef structures, and shell-based substrates that not only stabilise infrastructure but also create niches for lobsters, shellfish, and other crustaceans.
    - **Reef-type add-on**s are modular prefabricated structures that create artificial habitats such as Biohuts®[47] and fish hotels integrated into turbine foundations.
    - **Water replenishment holes,** originally intended to reduce corrosion, can be used to create microhabitats, and reef-like concrete blocks or adapted rock protections.
- **Integration of biodiversity monitoring within routine asset inspections and maintenance** to measure ecological indicators, such as species presence, concurrently with collecting data from structural assessment.[48]
- **Design with end-of-life considerations in mind,** facilitating the reuse and recycling of components and reducing the amount of virgin materials needed to be mined or manufactured for new offshore wind farms.[49]

d Measures that are integrated into or added to the design of [offshore wind] infrastructures to increase suitable habitat for native species (or communities) whose natural habitat has been degraded.

Case study

**Red Electrica ecological sub-sea cable protection in the Canary Islands**[50]

ECOncrete units colonized by marine life (Source: Link)

As part of the sub-sea interconnection project between the islands of Fuerteventura and Lanzarote, Red Eléctrica, the Spanish transmission system operator, worked with ECOncrete to develop and deploy a bespoke ecological, concrete solution for protecting the cable along its sub-sea trench. ECOncrete incorporated recycled and supplementary materials to address Red Eléctrica's challenge to cap the cable trench in the rocky seabed between the islands. Conventional cable protection methods typically use plain concrete or rock dumps, which have significant environmental footprints but provide no benefits to local ecosystems. This alternative solution was required not only to safeguard the cable but also to support and enhance the surrounding marine ecosystem and its biodiversity.

What makes this project particularly valuable for future infrastructure development is the rigorous scientific approach to monitoring ecological outcomes. The two companies have launched a monitoring study with the main objective of assessing biological growth within the ECOncrete cable protection solution (trench protection units) and the surrounding reef, including detailed documentation of species composition and measurement of biodiversity indices.

Two years after installation, marine life is thriving along the route and the cable protection has merged with the natural marine habitat, to the extent that the installation is in most parts invisible to the naked eye. This biological diversity demonstrates true ecological integration, with the artificial structures now functioning as natural reef environments.

Case study

**Fish Hotels in Hollandse Kust Noord, Netherlands**[51]

Dutch transmission system operator TenneT partnered with marine ecology specialists Ecocean to enhance biodiversity at their Hollandse Kust Noord wind farm located 18.5 kilometers off the west coast of the Netherlands. The collaboration, which began in 2021, involved installing innovative 'fish hotels' on the jacket legs of the offshore high voltage station.

These structures consist of metal frames that each house three 'biohuts' filled with oyster shells. Their design creates protected spaces where young fish can shelter from predators whilst finding abundant food sources, boosting local fish populations and supporting a wider network of marine life. .

Fish hotels attached to offshore high voltage stations, operator: TenneT, North Sea, Netherlands (Source: Link, Photo by: TenneT)

Engineers designed these fish hotels with durability in mind, ensuring they would withstand the harsh North Sea environment. Initial inspections have confirmed that the structures remain intact and functional. Their positioning above the seabed represents a thoughtful design choice that reduces both predator exposure and sediment accumulation that might otherwise compromise their effectiveness.

TenneT has begun its first ecological monitoring programme, employing sophisticated techniques including Remotely Operated Vehicle imaging and environmental DNA analysis. The early results appear promising, as TenneT has already integrated fish hotels into their technical standards for upcoming offshore platforms.

## Ports

Shipping and ports enable over 80% of world trade, yet at the same time their development and operations place significant pressure on natural ecosystems through air and water pollution, underwater noise, dredging, land reclamation, and the introduction of invasive species via ballast water. These pressures contribute to biodiversity loss, disrupt sediment dynamics, degrade water and air quality, and create cumulative environmental burdens extending from coastal zones into adjacent inland ecosystems.

'Green ports' refer to ports that are designed and operated to minimise environmental impact while promoting efficient resource use. They integrate sustainable practices across operations, such as reducing emissions, through a combination of technological, infrastructural, and management measures. The goal is to balance port development and economic demand with environmental protection and community wellbeing.[52]

More recently, ports are starting to embrace development approaches that go beyond decarbonisation, aiming to protect and actively restore natural ecosystems, enhance biodiversity, and strengthen community resilience. These strategies are increasingly being institutionalised through Integrated Port Management (IPM) frameworks, which align biodiversity and ecosystem health considerations across the entire lifecycle of port development, from site selection and design to operation and monitoring.[53]

More recently, ports are starting to embrace development approaches that go beyond decarbonisation, aiming to protect and actively restore natural ecosystems, enhance biodiversity, and strengthen community resilience.

Nature-positive solutions currently being implemented in the context of ports draw from established approaches such as Working with Nature[54] and those presented for coastal protection. Some examples include:

- **Natural wave protection solutions,** such as sandbar or submerged breakwaters, dissipate wave energy naturally and protect the port while creating shallow water nursery areas for juvenile fish and invertebrates. Another example is living reefs of oysters and mussels, which serve as natural breakwaters while filtering water and creating complex habitats for a diversity of marine species.
- **Marine protection structures and living seawalls** can be enhanced with ecological features. These specialised concrete formulations promote biological colonisation and shaping surfaces with cavities and textures to encourage marine life colonisation.
- **Artificial substrates and floating structures** can be put in place in areas where natural restoration proves challenging, improving water quality and enhancing coastal resilience without compromising essential infrastructure functionality.
- **Clean dredged material** from port maintenance activities offers valuable opportunities for habitat creation, supporting wetland restoration, beach nourishment, and the establishment of nature reserves to offset the ecological impacts of port development.
- **Water quality and pollution control innovations** include advanced treatment technologies and near real-time monitoring systems that reduce pollutants entering marine environments, effectively managing runoff, oil spills, and chemical discharges. Reducing pollution in ports protects marine life, ensures safe operations, and benefits local communities reliant on fishing and recreation.

Case sudy

**How sand can protect both the ports and nature: The Lekki Sandbar Breakwater, Nigeria[55]**

The Lekki sandbar breakwater at Dangote's marine terminal in Lagos State, Nigeria, exemplifies how natural sand movement processes can be used to form a defense that protects port infrastructure while enhancing coastal ecosystems.

Aerial view of the small-scale, nature-driven sand engine, Lekki, Lagos State, Nigeria (Source: Link, Photo by: Boskalis and CDR)

Engineers from CDR International and Svašek Hydraulics designed a breakwater made mainly out of sand. Using state-of-the-art mathematical modeling, the sandbar breakwater is strategically positioned to block the most powerful waves, protecting the ships and port infrastructure. The design includes a 'sand engine' – an area where sand naturally accumulates and then gradually feeds back into the coastal system, helping to mitigate downdrift erosion and stabilise the shoreline.

Instead of destroying intertidal zones (the areas that are underwater at high tide but exposed at low tide) as traditional rigid structures like concrete walls often do, this design expanded these critical habitats. The sandbar breakwater can naturally adapt to changing conditions, including sea-level rise caused by climate change. As water levels rise, the sand naturally redistributes to maintain its protective function.

The project has already demonstrated its value, with new beach areas forming that have been incorporated into the terminal's expansion. Rather than degrading over time like traditional infrastructure, this natural system actually improves as it settles into equilibrium with local conditions.

**Case study**

**Making Westport People- and Nature-positive, Western Australia**[56]

Westport, integrates seagrass management as part of a broader initiative that combines advanced technology, environmental monitoring, community engagement, and innovative port design.

Westport initially conducted comprehensive investigations to identify critical components of the natural system, recognising seagrass as the essential asset to protect in their port development plans. They mapped over 4,000 hectares of seagrass across four marine zones, using this data to inform strategic decisions.

Aerial view of the existing Kwinana port a site of the Westport project, Western Australia (Source: Link)

Based on this understanding, Westport relocated the port footprint one kilometre south to avoid large-scale seagrass removal, reducing direct impacts to just 2% of existing meadows. Beyond protection, Westport is leading restoration efforts, collaborating with the Western Australian Marine Science Institution to improve understanding of seagrass resilience.

The initiative incorporates innovative technology, including Australia's first trial of robotic seagrass planting equipment that injects seeds directly into sediment to enhance germination rates. This approach is complemented by comprehensive stakeholder engagement and a long-term environmental monitoring programme that enables adaptive management of restoration efforts.

# Challenges and barriers to implementing Nature Positive Engineering

Despite clear benefits, the consultation and research have highlighted several challenges and barriers to the implementation of NPE approaches and solutions across multiple domains.

## Systemic barriers to mainstreaming NPE

A central challenge for advancing NPE is that nature-positivity is not yet a standard part of the engineer's brief. Infrastructure projects still prioritise conventional performance metrics -cost, efficiency, safety, and compliance – while ecological outcomes are often treated as secondary or optional. This is reinforced by enabling environments that favour traditional infrastructure approaches, including policy and regulatory frameworks that overlook nature-positive requirements and financing mechanisms that fail to adequately value ecosystem services. Embedding NPE into routine practice will therefore require systemic change, with nature-positive principles integrated into planning, permitting, procurement and investment processes.

Equally critical is the development of clear standards and technical guidance that provide engineers with the confidence to design and deliver nature-positive solutions. In the absence of consistent benchmarks, projects risk being seen as experimental rather than replicable models for wider adoption. At the same time, building professional capacity is essential: engineers will need new skills, tools, and modes of interdisciplinary collaboration to integrate ecological knowledge into design and delivery. Overcoming these barriers will demand coordinated efforts across policymakers, regulators, professional bodies, and the engineering sector. Only through such systemic shifts can NPE move from the margins into the mainstream. These are further discussed in the Implementation Pathways chapter.

### Inadequacy of measurement and monitoring

Measurement and monitoring is a core tenet of NPE implementation as it forms the empirical foundation for engineering and evidence-based decision-making and justifying investment in nature. However, the current landscape of ecological measurement and monitoring faces several significant challenges that impede comprehensive environmental assessment and management.

Selecting appropriate metrics depends on measurement purpose, operational scale, and data availability.[57] Metrics need to reflect not only ecological performance but also contextual realities, including local priorities, capacities, and knowledge systems.

### What are we measuring?

The health of marine ecosystems can be assessed through multiple indicator types:[58]

- **Biological indicators** track population trends and ecological roles (e.g. species abundance, biodiversity, keystone/invasive species)
- **Physical indicators** reveal environmental stability (e.g. water quality, carbon sequestration, hydrodynamic conditions)
- **Functional indicators** assess ecosystem services, habitat connectivity, and resilience
- **Human pressures** measured through fishing intensity, pollution, and coastal development
- **Management effectiveness** evaluated through marine protected areas and community engagement, capturing local knowledge systems.

Scale of measurement – in terms of measurement scope (project to planetary), timescale (short-term versus long-term outcomes) and spatial resolution (individual species to full ecosystems) – is a fundamental challenge for NPE implementation.[59]

There is a disconnect between local to global impacts. At the project level, it is vital to define clear, project-specific metrics early in the planning phase to better Link environmental monitoring with operational and financial decisions. These are essential for understanding the direct impacts of local actions and fulfilling regulatory requirements or voluntary commitments by companies and developers. However, global goals – such as those articulated under the Global Biodiversity Framework – require aggregation, tracking change in biodiversity and function at larger spatial and time scales.

A further scale-related challenge is the distinction between attribution and contribution. At the site or project level, stakeholders often aim to attribute biodiversity outcomes directly to specific interventions they have taken. However, at larger scales, particularly in national reporting or corporate disclosures, the question shifts to contribution: how does this activity contribute to broader biodiversity trends? Given the number of existing variables, (e.g. climate, land-use change), direct attribution becomes nearly impossible.

To monitor progress, nature-positive outcomes must be aggregated across sites, sectors, companies, and countries. This is a formidable challenge given the diversity of ecological contexts and data types. Without a common measurement framework, these diverse efforts cannot be meaningfully compared. Efforts like the State of Nature Metrics[60] and the Biodiversity Indicators Partnership,[61] and frameworks such as the Science Based Targets for Nature (SBTs)[62] and Taskforce on Nature-related Financial Disclosures (TNFD)[63] are working to align indicators. The push for standardisation must balance rigour and flexibility, allowing for contextual relevance while maintaining enough consistency to enable broader tracking.

## Lack of ecological baselines

'Nature-positive' requires demonstrable improvements against defined baselines, which provide essential reference points for assessing intervention effectiveness over time.[64] A critical implementation barrier is the persistent absence of robust ecological baselines, particularly in marine ecosystems where biodiversity complexity makes tracking inherently challenging. Compounding this challenge are missing or inconsistent baseline data, [65,66] non-standardised monitoring methods,[67] and unresolved questions about long-term funding responsibilities, especially beyond initial project phases.

Technical barriers include high costs, logistical difficulties in data collection, and concerns about data quality and verification. Current approaches often marginalise crucial qualitative insights, traditional knowledge, and local community perspectives, whilst regulatory frameworks lag behind technological innovations, creating uncertainty in compliance and data utilisation. The complexity of marine environments, jurisdictional variation, and fast-changing ecological conditions[68] all pose significant challenges. Weak environmental and hydrodynamic models make it difficult to predict ecosystem changes or measure intervention success.

## Complexity of ecological dynamics

Ecological change unfolds across multiple spatial and temporal scales, creating significant challenges for biodiversity management and nature-positive engineering. A persistent issue in biodiversity offsetting is the temporal mismatch between immediate biodiversity losses and gains that may only materialise years or even decades later. Localised benefits from projects can also mask broader risks, such as regional ecosystem fragmentation or the disruption of species migration corridors. These complexities are especially pronounced for infrastructure that integrates natural elements, which rarely respond to stress in simple or linear ways. As engineered systems increasingly interact with dynamic ecological processes, their performance becomes harder to predict, particularly under shifting climatic conditions.

## Evidence gap

Evidence on the safe implementation and long-term effectiveness of such solutions remains limited. While pilot projects demonstrate promising near-term benefits, few are supported by long-term monitoring programmes that can track ecological outcomes, safety, and resilience over time. This lack of evidence, combined with the high costs of monitoring, constrains our ability to evaluate effectiveness and establish robust design standards. Learning from implementation is therefore critical – not only to assess long-term safety and ecological implications, but also to identify unintended consequences for ecosystems and communities. To move beyond the pilot mentality, lessons need to be consolidated and scaled, helping to close the evidence gap and strengthen confidence in nature-positive approaches.

# Emerging trends and opportunities in nature-positive engineering

## Innovation and technology for measurement and monitoring

Addressing measurement and monitoring challenges requires a varied approach: developing open-access data repositories, standardising monitoring frameworks, investing in scalable technologies, and integrating diverse knowledge systems to generate more comprehensive and actionable environmental insights.

Industry, academia, governments and civil society are beginning to explore more integrated, dynamic and inclusive approaches to monitoring. Advanced monitoring technologies offer promising improvements in data resolution, scalability, and cost-efficiency, crucial to long-term assessment of biodiversity and ecosystem health indicators. Examples include: eDNA[69], AI-powered drones and video analysis[70], Autonomous underwater vehicles (AUVs)[71], Light Detection and Ranging (LiDAR), Satellite-based earth observation methods[72], and Digital twins[73], see Annex 3 for more details.

Artificial Intelligence (AI)-powered monitoring systems are becoming increasingly necessary to respond to the speed and complexity of environmental changes. Improved measurement and monitoring of marine biodiversity and ecosystem health create valuable opportunities for citizen science and stakeholder engagement by making data collection more accessible, transparent, and participatory.[74] Affordable technologies like mobile apps, drones, and low-cost sensors empower local communities, fishers, and volunteers to contribute observations, expanding geographic and temporal coverage beyond what professionals alone can achieve.

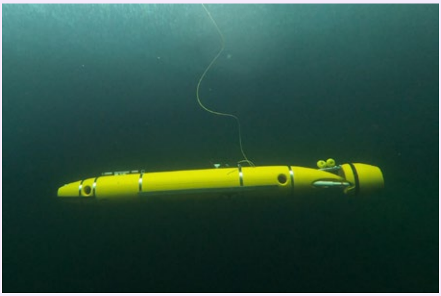
Case Study

**Leveraging advanced technology for biodiversity monitoring: The SeaMe Project, Germany**[75]

RWE's SeaMe project at the Kaskasi offshore wind farm in Germany marks a shift towards ecosystem-based, low-emission biodiversity monitoring in the offshore energy sector. Running from 2024 to 2026 in partnership with marine research institutes, the project employs advanced technologies to assess marine biodiversity with minimal environmental disturbance.

RWE's artificial reefs at an offshore wind farm, Baltic Sea (Source: Link)

SeaMe replaces traditional ship-based sampling with a suite of innovative tools. AI-powered drones monitor resting and migratory birds around the clock, reducing the need for offshore human observers, enhancing safety, and cutting emissions. Underwater, autonomous vehicles equipped with AI-driven cameras observe fish and other marine species non-invasively. These systems also collect continuous data on water conditions such as temperature and salinity, offering greater temporal resolution than conventional annual surveys. eDNA analysis complements visual methods, detecting genetic traces of native and invasive species in water samples. SeaMe's holistic approach integrates data across multiple ecosystem components, enabling better identification of ecological stressors and cumulative impacts. Designed as a replicable model, SeaMe demonstrates how offshore wind farms can adopt ecosystem-centred technologies to monitor biodiversity outcomes while advancing the global clean energy transition.



SeaMe ecosystem monitoring drone (Source: Link)

Alongside technological innovation, industry-led frameworks are shaping how monitoring is embedded into project planning and evaluation, integrating risk screening, baseline data collection, impact modelling and action planning to support net-positive outcomes.

## Case Study

**Ørsted's Biodiversity Measurement Framework**[76]

Ashley Dace/Wikimedia Commons

Ørsted, an industry leader in offshore wind development, has developed an eight-step biodiversity measurement framework to ensure that its renewable energy projects enhance, rather than harm, biodiversity. This framework is designed to assess the impacts of offshore wind farms on marine ecosystems throughout the lifecycle of the projects, from planning and construction to operation and decommissioning. Launched in 2024 in collaboration with The Biodiversity Consultancy, the framework aligns with global standards such as the Science Based Targets Network (SBTs)[77] and the Taskforce on Nature-related Financial Disclosures (TNFD), and aims to achieve a net-positive biodiversity impact for all new projects from 2030 onwards.[78]

A cornerstone of the approach is the identification of 'priority biodiversity features' – specific habitats or species that are contextually relevant to each project and form the basis of tailored assessment and management. This ensures that the most relevant aspects of biodiversity are accurately measured and integrates monitoring to track progress and inform adaptive management strategies.

There is growing emphasis on data-sharing platforms, cross-sectoral collaboration, and more decentralised approaches that can reflect local priorities and conditions. Public sector accountability and access to environmental data are crucial for effective nature-positive solutions.

Initiatives like the Marine Natural Capital and Ecosystem Assessment Programme[79] demonstrate how comprehensive data collection can inform engineering decisions. However, current approaches remain fragmented; while Environmental and Social Impact Assessments (ESIAs) are standard, post-construction biodiversity and marine ecosystem health tracking is rarely mandated.[80] Some protocols, frameworks and resources exist and should be leveraged by scientists and practitioners, such as the Global Ocean Observing System (GOOS),[81] the Marine Biodiversity Observation Network (MBON),[82] and the Ocean Best Practices System (OBPS).[83] Increased collaboration and alignment among institutes would improve our chances of achieving national and regional objectives to achieve good ecological conditions in the marine environment.[84]

### The Marine Data Exchange Platform, UK[85]

The Marine Data Exchange Platform is a government-supported initiative designed to facilitate the sharing of marine data across various sectors in the UK. It serves as a centralised hub for accessing marine-related data, with the aim of improving decision-making, research, and policy development in marine and coastal environments.

### The Ocean Data Platform, global[86]

The Ocean Data Platform by HUB Ocean is a free, cloud-based geospatial system that harmonises diverse ocean datasets from public and private sources. The platform is designed for interoperability in a federated ocean data ecosystem and allows users to seamlessly upload, combine, and analyse ocean data through a shared workspace. Designed for researchers, policymakers, and industry professionals, it enables rapid insights for ocean governance, conservation, and sustainable management decisions.

## Learning from success and failure

As we accelerate the deployment of nature-positive engineering across sectors, there is an opportunity to improve how we share knowledge about what works, providing systematic documentation and analysis of both successes and failures.

Scaling effective NPE solutions will require capturing and sharing evidence and insights from diverse implementation contexts, understanding the factors that influence project outcomes, and translating those lessons into better design and delivery. Some examples of interventions that have led to unintended consequences are presented below.

### Case Study
**Chao Phraya Delta, Thailand**[87]

Thailand's Chao Phraya Delta provides a cautionary example. Bamboo fences were installed to facilitate mangrove regeneration, but the project designers hadn't adequately accounted for the area's high land subsidence rates and insufficient sedimentation. As a result, the bamboo structures degraded within just a few years, creating debris that obstructed coastal access. Without enough sediment accumulation, mangroves failed to establish, and the project ultimately caused environmental degradation rather than the intended protection. Local communities, who might have offered valuable insights during planning, ultimately disapproved of the approach due to these negative outcomes.


Jack Suvarnabhumi/Shutterstock

Case study

**When grey infrastructure falls short: the MI COSTA project in Cuba[88]**

Cuba is increasingly vulnerable to climate change impacts, particularly along the southern coast. By 2100, five communities along the 271 km stretch from La Coloma to Surgidero de Batabanó could disappear due to sea level rise. The critical concern is saline intrusion into the aquifer system supplying freshwater to coastal communities, agriculture and Cuba's capital city, La Havana.

In 1991, the government built the Southern Dike, a 51.7 kilometre levee costing $51.3 million to block saltwater infiltration. While partially effective for its primary purpose, this traditional 'grey' infrastructure approach led to mangrove degradation on its northern shore, reducing their coastal protection function. The dike also incurred $1.5 million in maintenance costs every 3 years, and required a one-time $15 million expenditure 20 years after construction. In response, The Green Climate Fund project 'Coastal Resilience to Climate Change in Cuba through Ecosystem Based Adaptation' ('MI COSTA'), started in 2021. Scheduled for completion in 2028, MI COSTA aims for a holistic, nature-positive approach to climate adaptation by restoring mangroves and coastal ecosystems that provide natural protection with multiple co-benefits and lower maintenance costs, and by building the capacity of coastal governments and communities.

Mangrove restoration, MI COSTA project, Cuba (Source: Link, Photo by: UNDP)

Going forward, better mechanisms are needed to create a global knowledge base that prevents repeated mistakes. Good examples of structured knowledge sharing knowledge and learnings, such as the Safety in Search And Rescue initiative by the International Maritime Rescue Federation,[89] might be adapted and replicated.

Ways to prevent or manage unintended consequences include conducting comprehensive risk assessments that fully consider local environmental conditions and community perspectives before implementation, ensuring solutions are tailored to specific contexts.

Once projects commence, continuous monitoring throughout their lifecycle, with built-in mechanisms to adapt when issues arise, allows for timely course corrections. High-quality environmental data requires substantial investment and must be budgeted upfront. When properly funded, comprehensive monitoring enables more efficient project execution, ultimately reducing overall costs through better decision-making and reduced environmental risks.

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Case study

**Learning from long-term monitoring: the WinMon.BE programme, Belgium**

Since the first offshore wind turbine installation in 2008 in the Belgian part of the North Sea, the WinMon.BE programme[90] has assessed the environmental impacts of offshore wind across the full project lifecycle. Led by a consortium of national research institutions, the programme provides invaluable evidence on the performance of nature-positive approaches.

Image 11 – Wind farms on the North Sea, WinMon.BE monitoring programme, Belgium (Source: Link)

Over 15 years, monitoring has revealed important and sometimes unexpected ecological dynamics.[91] Seabed surveys show increased biodiversity near turbines, where enriched sediments support diverse macrobenthic communities. Studies on fish living and feeding on or near the bottom of seas suggest wind farms may serve as fishing refuges, though the long-term ecosystem effects remain under investigation. Seabird studies reveal species-specific responses; some avoid turbines, while others are attracted to them, prompting interest in mitigation strategies such as temporary turbine shutdowns during migration periods.

The WinMon.BE programme experience demonstrates how sustained, adaptive monitoring yields actionable insights for nature-positive ORE design. Lessons learned have influenced national policy and regional cooperation through initiatives like the Greater North Sea Basin Initiative.

## Developing solutions that are Nature- and People-positive

The 'Nature Positive' philosophy holds that a healthy environment is only achievable through social inclusion and equity, while delivering benefits to all people.[92,93] This approach acknowledges nature's intrinsic value alongside its vital contributions to human safety, wellbeing, and prosperity,[94] echoing wisdom long held by many indigenous communities.[95] NPE offers engineers a unique opportunity to become stewards of the natural environment, demonstrating that infrastructure development and nature recovery can be mutually reinforcing. Success requires transparent acknowledgement and proactive management of trade-offs, alongside co-development of solutions with local communities who will ultimately inherit and maintain these systems.

### Being honest about trade-offs

**Despite the deep interconnections between the challenges we face, we continue to approach them in isolation.** The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Nexus Assessment warns that this siloed approach creates misalignment and unintended consequences.[96] When we protect biodiversity without considering impacts on communities, we risk creating new problems whilst solving others. This complexity calls for 'nexus approaches', which recognise and respond to these connections.

A **nexus approach** is about applying systems thinking to understand the interlinkages and interdependencies between sectors and systems in a holistic manner and to develop integrated and adaptive decisions that aim to maximise synergies and minimise trade-offs.[97]

In the context of NPE, the **climate–nature–health nexus** refers to the interconnected relationship between climate change, natural ecosystems, and human health. It highlights how disruptions in one area can cascade across the others, creating risks but also opportunities for integrated solutions.

**Nature takes time to recover and replenish.** Ecological benefits often take decades to appear, while political and economic systems usually focus on short-term gains. This mismatch can lead to unfair outcomes, with nature-positive measures in the short term having uneven impacts, benefiting some members of a community more than others.[98] For example, establishing a marine protected area might help fish populations recover and benefit tourism operators, but it could simultaneously restrict access for small-scale fishers who have relied on those waters for generations. Spatial trade-offs are inherent in infrastructure development, as demonstrated by offshore renewable energy, where local disruption must be balanced against broader climate benefits and societal demand for renewable energy.[99]

Instead of striving for idealised perfect solutions, **we must focus on systematically understanding and managing trade-offs, ensuring adequate support for those most impacted – whether people or nature.**[100] Evaluation frameworks should provide recommendations on how we can ensure equitable growth and consider whether solutions will remain effective under changing future conditions. Using advanced data-driven approaches and visualisation tools can help to quantify impacts and aid decision-making. To support this, a variety of analytical tools are available to help Link environmental and societal outcomes.[101]

## Co-developing nature-positive solutions

**Nature-positive solutions must be co-developed with Indigenous Peoples and local communities,** respecting their rights, valuing their knowledge such as holistic views of ecosystem interconnections, that are often overlooked in conventional science[102], and ensuring they share the benefits.[103] Meaningful engagement requires honesty about potential impacts, early and continuous involvement, and active protection of marginalised groups who often rely on nature but lack a voice in-decision making. Treating these communities as trusted advisors increases the likelihood of success and supports long-term environmental and social outcomes.[104]

While participatory processes which include local voices are gaining traction, challenges remain in ensuring fair distribution of benefits, especially when improvements risk displacing lower-income groups or traditional users like small scale fishers.[105] Innovative tools such as gamification,[106] visualisation platforms,[107] and digital engagement can support inclusive dialogue and empower communities to shape nature-positive futures.

Local community engagement demands careful planning, inclusive participation, and adaptability when conflicts arise – it is rarely quick, easy, or low-cost. It also involves addressing economic concerns through benefit-sharing models and fostering community stewardship via education and sustainable livelihoods aligned with local interests.[108]

**Case study:**

**Aligning cultural values with coastal protection: the 'Barachois' seascape in Mauritius[109]**

The Barachois are unique coastal lagoons in Mauritius – shallow water bodies enclosed by traditional stone walls that locals historically used for fish farming. These culturally significant sites, along with surrounding mangroves and coastal forests, had deteriorated into neglected waste dumping areas.

The Environmental Protection & Conservation Organisation (EPCO) launched a community restoration project to revive the Barachois seascape and improve local livelihoods while promoting biodiversity conservation.

Aerial view of a barachois, Mahebourg, Mauritius (Source: Link, Photo by: John Olsen)

Restoration efforts focused on planting native vegetation, removing invasive species, and rebuilding the traditional stone walls using local materials. Engineers helped optimise the size of openings in the new walls to harness tidal action for natural water circulation, creating optimal conditions for cultivating oysters, mud crabs, and other marine life. EPCO facilitated the formation of a local management group that bridges community knowledge with technical expertise.

The project gained strong community support by addressing local priorities including fish breeding habitat, recreational spaces, and environmental education opportunities. EPCO provided training in business skills and conservation practices, which helped reduce fishing pressure on surrounding coastal areas and created alternative livelihood opportunities. The collaboration between EPCO, government agencies, and local residents offers a replicable model for coastal wetland management that prioritises traditional knowledge and natural processes over complex engineering solutions.

## Designing for nature under climate stress

A clear trend in NPE is the move toward solutions that can perform reliably under conditions of ecological and climatic uncertainty. Climate models increasingly project a likely overshoot of 1.5°C,[110] with complex, potentially irreversible consequences for natural systems.

A critical consideration for NPE is how to plan for scenarios where ecosystems no longer function as expected. For example, low-crested artificial breakwaters, an engineered solution that can be combined with natural elements, may perform well in temperate regions but is less effective in tropical environments, where coral reefs provide superior wave attenuation at lower cost and with minimal maintenance. Yet, under ocean acidification scenarios, coral reefs themselves may degrade, compromising their protective function.

**Addressing these uncertainties demands a shift toward adaptive, flexible engineering approaches** that can evolve in response to ecological feedback and new information. A better understanding of ecosystem dynamics under climate stress would enable NPE to deliver more resilient, future-proof solutions and minimise unintended consequences. Further research and modelling are urgently needed to assess how ecosystem-based interventions will perform under a range of climate scenarios.[111]

Yet uncertainty must not become an excuse for inaction. Significant expertise exists across engineering, ecology, and climate science, and emerging technologies such as remote sensing and AI-powered modelling are improving our capacity to assess, manage, and refine NPE interventions. Comprehensive monitoring systems will be key to adaptive management. Achieving this will require interdisciplinary collaboration and rapid investment in high-resolution data collection and scalable monitoring technologies – an area where the industry is already beginning to advance.

# Scaling the uptake and impact of nature-positive engineering

Scaling up NPE implementation requires coordinated action across three complementary pathways:

## Pathway 1: Creating an enabling environment for the nature-positive transition

### Policy and regulation

Policy, planning, and regulatory frameworks[112] are crucial enablers, and sometimes barriers, to the widespread adoption of nature-positive approaches in infrastructure sectors globally.

The Global Biodiversity Framework[113] explicitly integrates NbS – a key suite of solutions that can be implemented through NPE – into climate adaptation and urban development but lacks explicit references to nature positivity or ecological regeneration. Whilst international agreements like the GBF set important goals, they often fail to account for governance capacity, resource limitations, or socio-political dynamics in diverse settings.

At national levels, promising policies are emerging and they offer a significant opportunity to embed requirements to protect nature while meeting societal needs. Countries are starting to incorporate NbS and ecosystem-based adaptation in their climate policies such as National Adaptation Plans (NAP), a notable example is Uruguay's Coastal NAP that explicitly incorporates nature-based approaches to flood management. The Brazil Blue Initiative,[114] launched by the Government of Brazil with support from international partners such as the Inter-American Development Bank (IDB) and the United Nations, has the potential to become a policy enabler and coordination mechanism for integrating nature-positive principles into Brazil's coastal and ocean development. In Europe, policies requiring biodiversity improvements are advancing, including the EU's Nature Restoration Law[115] and the UK's Biodiversity Net Gain policy and emerging Marine Net Gain concept.

### Biodiversity Net Gain and Marine Net Gain in the UK

The UK's **Biodiversity Net Gain (BNG)**[116] policy, formally implemented in England in 2024 under the Environment Act 2021, requires most new developments to deliver a measurable 10% net gain in biodiversity. BNG must be secured for at least 30 years through on-site habitat creation or enhancement, off-site compensation, or the purchase of statutory biodiversity credits as a last resort. Technical guidance on how to implement the BNG policy in a robust and evidence-based way is currently being produced.

While BNG currently applies only to terrestrial and intertidal habitats in England, the UK government is exploring a parallel concept of **Marine Net Gain (MNG)**[117] for English waters. MNG would aim to improve the state of the marine environment by considering both biodiversity and ecosystem services, but its scope, metrics, and legal mechanisms are still under development.[118] Unlike BNG, MNG faces unique challenges such as dynamic and interconnected marine ecosystems, limited baseline data, and unclear property rights at sea.

Though voluntary frameworks have built momentum and established best practices, binding regulations are essential, as incentives remain limited when practices appear to increase costs or complexity. A common challenge across sectors and regions is the fragmentation of regulatory frameworks, and weak and under-resourced enforcement mechanisms. Particularly in marine and coastal environments, jurisdictional complexity and unclear responsibilities between local, national, and international bodies complicate the implementation of NPE.

Regulations vary widely across national and regional contexts, with inconsistent requirements, permitting processes, and environmental performance standards. This is especially visible in the ports and shipping sector, where infrastructure often spans both terrestrial and marine jurisdictions. Most planning systems and building codes typically favour traditional 'grey' infrastructure, with standards and permitting processes unintentionally discouraging NPE solutions due to unfamiliarity or perceived performance uncertainty. Regulatory processes often require evidence of safety and long-term durability, creating obstacles for approaches relying on dynamic living systems.

## Emerging trends and opportunities in policy and regulation

Policy maturity varies significantly across marine sectors. In the coastal sector, emerging approaches include integrated shoreline management plans with greater regulatory authority and ICZM (integrated coastal zone management). Momentum is building towards fully costed, locally managed coastal adaptation plans[119,120] supported by marine spatial planning and participatory environmental management. However, governance gaps persist where donor requirements, national policy, and community priorities misalign.

Regulatory fragmentation and the lack of sector-specific incentives remain core barriers in the port sector. While integration of NbS into certification schemes – such as the Green Port Award System (GPAS)[121] or EcoPorts[122] – shows progress, systemic policy reforms are needed to embed NPE approaches in port development. Emerging policy dialogues are exploring NPE solutions in ports, with growing interest in aligning port development with marine spatial planning and biodiversity objectives. The trajectory is moving towards global frameworks or regional agreements that embed mandatory biodiversity targets into port certification, financing, and permitting processes. The IMO's environmental regulations, notably those reaffirmed and advanced during the MEPC 83 session,[123] play a crucial role in bridging gaps in decarbonisation and biodiversity protection within the maritime sector.

Regulatory frameworks in the ORE sector tend to be more advanced, although policies often focus on impact mitigation rather than ecosystem restoration. Emerging discussions around Marine Net Gain[124] represent a promising opportunity to strengthen biodiversity requirements for ORE projects globally. In the near future, regulatory pathways are likely to shift towards formalising nature-positive requirements beyond just increasing biodiversity, incentivising regenerative design approaches, and embedding ecological monitoring throughout project lifecycles.

Embedding ecological and engineering expertise in planning and regulatory processes, alongside improved monitoring systems and data transparency, will be essential to ensuring that NPE moves to standard practice globally. Across all sectors, alignment of marine spatial planning policies, tools and blue economy[125] frameworks will also shape how nature-positive approaches become operationalised at scale. **Procurement and permitting processes also present promising avenues to embed nature-positive requirements into infrastructure development.**

Engineers can help overcome policy barriers by highlighting safe and sustainable NPE solutions that are most likely to maximise benefits and balance trade-offs, and by strongly advocating to move away from policies and interventions that are particularly harmful for our planet, such as burning fossil fuels and uncontrolled consumption of natural resources.[126,127]

## Finance

Halting and reversing biodiversity loss is no longer just an environmental imperative but a critical financial strategy that can unlock tremendous economic potential. Analysis suggests that transitioning to a nature-positive economy could generate $10.1 trillion in business opportunities and create nearly 395 million jobs by 2030.[128] Action from all businesses, governments and financiers is needed if we are to realise positive change and avoid losing trillions over the next 15 years due to nature’s decline.[129]

The global ocean economy, currently valued at over $2 trillion and having doubled in the last three decades, supports millions of jobs and underpins the livelihoods of hundreds of millions of people.[130] Yet, in the last decade less than 1% of the total value of the ocean has been invested in sustainable projects, leaving a significant finance gap that threatens long-term economic resilience.[131] By closing this gap and prioritising the health of our oceans, we can unlock new business opportunities, create millions of jobs, and secure the essential ecosystem services that support life on Earth.[132]

**Nature-based infrastructure solutions are central to NPE, offering broader and more integrated benefits than traditional infrastructure.** These approaches reduce risks from floods, erosion, heat, drought, water scarcity, and landslides – while also restoring biodiversity, supporting tourism and recreation, and contributing to food, water, and climate regulation.[133] Despite its proven benefits, nature-based infrastructure is still not fully embedded in mainstream engineering. This is a missed opportunity. Nature-based infrastructure can deliver infrastructure outcomes at a lower cost and generate added value through ecosystem services, carbon credits, sustainable tourism, and increased property values. Integrating these solutions into the core of infrastructure development is essential for scaling NPE and unlocking greater economic returns.

## How can finance unlock NPE?

**Nature works on a different timeline than our financial world.** While investment markets prioritise quarterly returns, nature-positive approaches typically yield their most substantial benefits over decades which creates problems for financing nature positive infrastructure investments. Many financial stakeholders perceive nature-positive projects as cost burdens rather than investments, missing how deeply our economy depends on healthy natural systems.[134] For example, financial institutions generally categorise NbS as higher-risk investment propositions, particularly in developing economies with less stable policy environments and more constrained implementation capacities. The lack of clear evidence on long-term performance and the costs of monitoring environmental impacts makes these decisions even harder.

Compounding this challenge, **the financial consequences of not investing in nature, such as ecosystem degradation, disaster vulnerability, and reduced climate resilience, are rarely factored into economic analyses and decision frameworks.** As a result, the true value of nature-positive interventions is systematically underestimated.

To accelerate the uptake of nature-positive solutions, we need to rethink how economic success is defined and measured. This requires integrating natural capital into our assessments of wealth and performance, ensuring that the value of ecosystems is not treated as external to the economy.[135] Improved economic evaluation methods are essential to capture the full range of benefits these solutions provide. Their commercial viability also depends on making co-benefits clear and tangible for diverse stakeholders. By aligning nature-positive outcomes with financial interests, such solutions can drive market demand -delivering economic efficiencies, enhancing asset valuations, reducing insurance premiums, and lowering financial risks, while supporting a more resilient and regenerative economy.

### Natural Capital Accounting and Nature Valuation

**Natural capital** refers to the stock of natural resources that provide essential benefits to people. Recognising and valuing nature helps shift decision-making beyond short-term material gains toward long-term sustainability.

Natural Capital Accounting (NCA) is a method used to measure and record the value of natural resources and ecosystems in a way that reflects their contribution to the economy and society. In the context of oceans, it aims to quantify the stocks of natural capital (such as seagrass beds, mangroves, and coral reefs) and the flows of ecosystem services (like coastal protection, carbon storage, and fisheries support) they provide. NCA aligns development with environmental sustainability and long-term value creation. The UN's System of Environmental-Economic Accounting (SEEA) provides a framework for measuring these assets and services.[136]

Building on NCA, Nature Valuation identifies and assigns value to ecosystem services, highlighting nature's role in economic and policy decisions. Valuation can be monetary (e.g., avoided flood damage) or non-monetary (e.g., health or cultural importance), using methods like market pricing or cost-based approaches.[137] For example, the avoided cost of storm damage from healthy mangroves can be quantified, making their value tangible to policymakers and investors.[138]

NCA and Nature Valuation are crucial for integrating marine ecosystems into policy and finance, but – despite their importance – they face challenges in ocean contexts. A key issue is the lack of comprehensive data,[139] while scientific uncertainties limit model reliability. Many ocean ecosystem services, such as cultural or spiritual values, are difficult to quantify and often excluded from monetary valuation. Additionally, valuation methods may overlook local or indigenous perspectives, potentially commodifying nature. Even with available assessments, weak institutional capacity and limited policy integration can prevent their use in decision-making.

## Emerging trends and opportunities in finance

**Nature finance is gaining momentum through several promising innovations and efforts,** though substantial scaling is still needed to close the significant biodiversity funding gap.[140] Realising this shift requires updated regulations, improved data and technology,[141] and stronger cross-sector collaboration.[142]

Global consensus[143] is building through frameworks like the Global Biodiversity Framework.[144] Sector-specific guidance for industries such as offshore wind and ports is helping financial institutions align with biodiversity goals.[145,146]

Improved data is also accelerating progress. The Task Force for Nature Disclosure (TFND) framework[147] and regulatory initiatives like the EU's Corporate Sustainability Reporting Directive[148] are enhancing how companies report nature-related risks and opportunities. These tools enable more robust risk assessments, addressing a key barrier to scaling nature finance and by extension, scaling nature positive infrastructures.

Innovative financial mechanisms are emerging to reflect nature's value. Subsidies, credit systems, and biodiversity-linked investment standards are gaining traction. Blended finance models – where public funds take on higher-risk roles – are helping to attract private capital to nature-positive projects. The Blue Economy presents significant opportunities for nature-positive investments.[149] For example, energy company Ørsted issued the energy sector's first €100 million blue bond in 2023, focused on marine restoration and sustainable shipping.[150] Market-based tools like carbon and biodiversity credits create new revenue streams.[151]

Financial institutions have started integrating biodiversity into investment decisions. Leading banks and insurers are already applying these principles, including through circular economy strategies.[152] Multilateral development banks have laid important groundwork, recognising the interconnected goals of poverty reduction, climate action, and nature protection. They have developed principles[153] for identifying nature-positive investments that deliver measurable benefits without causing harm. However, enforceable standards and consistent requirements across financial institutions remain limited.

The insurance industry is gradually factoring nature into underwriting and investment to manage nature-related risks and improve resilience. New products are emerging, including nature-based debt instruments and parametric insurance, offering new ways to finance protection and adaptation while linking financial performance to ecological outcomes.[154]

When projects deliver coastal protection, carbon capture, and biodiversity improvements together, they become more appealing to investors. Multipurpose and multifunctional solutions that address several different needs or goals simultaneously create diverse revenue streams while providing environmental, social, and economic benefits.

### The Climate-Smart Shrimp initiative: A multipurpose green-grey-blue solution, Philippines[155]

Shrimp farming has historically damaged valuable blue carbon ecosystems like mangroves, salt marshes, and seagrasses. In the Philippines, shrimp aquaculture has contributed to the degradation of approximately 200,000 hectares of mangroves, almost 40% of the mangrove population. The Climate-Smart Shrimp initiative by Conservation International tackles this problem by combining responsible shrimp production with ecosystem restoration and regeneration.

Shrimp farm in the Philippines (Source: Link)

This initiative enhances farm productivity and profitability whilst simultaneously building environmental resilience. By integrating restoration with aquaculture, the project creates multiple value streams that attract diverse investment capital and offer a replicable model for sustainable blue economy development.

This multipurpose model uses green-grey infrastructure employing wetland treatment systems, restored mangroves, and clean energy infrastructure to deliver both economic returns and ecological improvements.

The initiative emphasises sustainable practices throughout the production cycle. Farms powered by renewable energy reduce their carbon footprint, supporting the transition to low-carbon food systems within the blue economy. Features like aerators and separate water channels improve production efficiency whilst eliminating polluting diesel pumps.

As the market develops and investor awareness grows, nature-positive finance is set to become a mainstream investment category that significantly contributes to global biodiversity and climate goals. In the future, nature is likely to be recognised as a distinct asset class,[156] supported by mature biodiversity and blue carbon credit markets and financial structures that reward nature-positive outcomes across sectors.

Given the central role of engineering in new infrastructure and retrofits, NPE can help unlock nature finance. Its focus on measurement and evidence aligns well with sustainability-linked finance models, where investment terms depend on environmental performance targets like biodiversity or carbon. NPE's emphasis on risk management also addresses concerns that nature-positive solutions may carry higher investment risk.

## Pathway 2: Building technical capacity for NPE

### Skills and education

Traditional engineering education does not adequately include NPE approaches and professionals must acquire new skills to be able to safely implement NPE measures, creating an urgent need for transformation. Lack of clarity on what NPE is, how to embed NPE in engineering workflows and engineering standards, and what they can do to protect, support and collaborate with nature are key challenges that need to be overcome with awareness raising, training and education.

Technical, behavioural, and cross-sectoral skills and competencies are required to implement NPE. Specific to NPE will be building competencies in environmental assessment, ecological restoration, natural capital accounting and valuation, scenario building, green-grey infrastructure techniques, and climate and nature finance mechanisms in addition to traditional engineering skills. Emerging green skills[157] frameworks – currently primarily focussed on decarbonisation and energy transition – could be expanded to include these competencies.

Engineers are increasingly expected to play a role as communicators, mediators, and leaders in sustainability efforts, including engaging with policymakers and the public, and should therefore be equipped to advocate for NPE approaches and solutions.

## Changing current practice

**Comprehensive capacity building will be needed to cultivate a new generation of practitioners who embed NPE principles at the heart of their professional identity.**

A clear struggle exists to balance traditional engineering approaches with emerging NPE concepts. However, integrated systems thinking is gaining momentum[158] as more professionals recognise the interconnectedness of nature and infrastructure systems.

Building capacity for interdisciplinary collaboration will be essential to achieving this, bringing engineers into closer collaboration with ecologists, social scientists, and policymakers. Upskilling efforts through continuing professional development (CPD) programmes, online courses, and real-world case studies are emerging as critical tools to bridge knowledge gaps. Professional certifications will also be important in incentivising upskilling and standardising industry knowledge.

Professional associations and industry bodies will play a key role in the mainstreaming of NPE approaches through sharing best practice, developing CPD courses, and setting standards and guidelines. Communities of practice, such as the Global Green-Gray Community of Practice,[159] can champion and disseminate best practices.

However, the responsibility for upskilling extends beyond engineers to include policymakers, regulators, investors, and the general public who need to understand why nature-positive approaches are crucial, how solutions can be deployed, and how to navigate associated risks, benefits, and trade-offs. Ultimately, engineers are guided by the demands of their clients – making it essential that decision-makers across all sectors are informed and aligned on the value of nature-positive solutions. For example, the revised EFRAG biodiversity standard (ESRS E4)[160] sends a strong market signal that clients will increasingly expect engineers to integrate nature-positive solutions into infrastructure design and delivery, as biodiversity outcomes become embedded in investment and reporting requirements.

New toolkits for the climate-nature-health nexus will be needed to equip engineers and other key decision-makers on how to manage the complex interconnections between natural and built systems.[161] Greater integration needs to emerge between different stakeholder groups, including government, academia, business, environmental organisations, and community groups. This integration can be supported by a common vocabulary and interdisciplinary platforms that facilitate knowledge sharing and collaborative decision-making, breaking down the traditional silos that have hindered effective implementation of NPE approaches.

Finally, NPE can attract environmentally conscious young people into the engineering profession and support retention. Organisations such as the Marine Technology Society (MTS)[162] are helping to meet this demand by fostering knowledge exchange, technical training, and early-career engagement in sustainable marine technologies, through technical symposia, active student sections, and certification opportunities. By emphasising NPE approaches and partnering with such networks, engineering can position itself as a field that offers meaningful work aligned with younger generations' values and aspirations to contribute to planetary wellbeing.

## Transforming engineering education

Current academic curricula tend to prioritise technical content, often neglecting environmental, economic, and social dimensions as well as the cross-disciplinary skills essential for NPE.

Ecological engineering, a discipline closely aligned with NPE principles, has a long history but remains underdeveloped academically, with curricula varying widely across institutions. There is a clear opportunity to establish a standardised global curriculum that integrates ecology, environmental management, engineering design, and sustainability science.[163] Transition Engineering[164] is an example of an emerging approach that incorporates long-term sustainability considerations into engineering education and practice. It focuses on managing changes in systems, technologies, and infrastructure in response to sustainability challenges.

Alongside reforming ecological engineering education, there is a pressing need to update curricula for all engineering disciplines. This could include, as a starting point, integrating ecology fundamentals into engineering degrees and providing opportunities for engineers to gain exposure to ecological concepts, while also imparting some engineering knowledge to ecologists. Systems thinking, anticipatory planning, and strategic foresight are increasingly seen as core components of engineering education.[165] Rather than treating sustainability as an add-on, these skills should be woven into the fabric of engineering education. Encouragingly, accreditation bodies have started embedding multidisciplinary competencies into engineering education programmes (e.g., ABET, UK Engineering Council) signalling a shift towards more holistic, sustainability-focused curricula.[166]

A gap still persists between academic training and industry expectations, alongside difficulties in effectively assessing sustainability competencies.[167] In response to this gap, experiential learning approaches, including hackathons, work placements and project work, are gaining traction. Integrating NPE principles in engineering curricula would help better prepare engineering students for the future job market. This could be done, as a first step, through the development of an industry-led knowledge module. Academia will be a pivotal lever in accelerating the uptake of NPE for future engineers; schools and universities should be encouraged to adopt curricula that reflect this opportunity.

Importantly, nature, climate and STEM education at a school level is also crucial to prepare young people for roles in NPE and apply a nature-positive lens from the start of their technical training.

## Guidance and standards for NPE

There is an urgent need to embed NPE approaches into mainstream standards and guidelines to accelerate their safe and effective adoption.

Learning from implementation plays a crucial role in building the evidence base needed to inform standards. Pilot projects provide vital opportunities to develop evidence on long-term safety implications, including potential unintended consequences for ecosystems and communities. However, these require extended monitoring before they can effectively inform technical design standards. **While we cannot halt progress waiting for standards to catch up, we must accelerate learning from existing projects in order to accelerate development of standards and technical guidance.**

## Building on the foundations of 'good engineering'

NPE doesn't require developing an entirely new engineering discipline. We can make significant progress by drawing from established, forward-thinking approaches such as Engineering With Nature, Building with Nature, circular economy principles, and climate change mitigation and adaptation strategies.

A lot of good guidance, case study compendia[168] and virtual resource libraries[169] exist, such as the 'Guide for Applying Working with Nature to Navigation Infrastructure Projects',[170] the 'Playbook on Nature-positive Infrastructure Development',[171] and the International Guidelines on Natural and Nature-Based Features for Flood Risk Management[172] – see more examples below.

### The Rich North Sea Toolbox[173]

The Rich North Sea Toolbox is a digital platform designed to support nature enhancement in offshore wind farms. Developed by The Rich North Sea programme – a collaboration between the North Sea Foundation and Natuur & Milieu – the Toolbox serves as a comprehensive resource for integrating biodiversity considerations into offshore energy projects. It combines scientific knowledge and practical experience to guide users in implementing nature-inclusive designs and restoration efforts.

Users can explore a variety of nature enhancement techniques, such as eco-friendly scour protection, tailored to specific marine species and habitats. The platform features an interactive map showcasing real-world projects across the North Sea, offering insights into successful applications of these methods. Additionally, the Toolbox provides practical information on regulatory requirements, permitting processes, and supplier contacts, facilitating the initiation and execution of nature-positive initiatives.

**Toolkit for Sustainable Port Development in a Blue Economy**[174]

Released in June 2023 by the Nairobi Convention Secretariat and the Council for Scientific and Industrial Research (CSIR), this toolkit offers a strategic framework for promoting sustainable port development in the Western Indian Ocean (WIO) region.

Building upon the 'Green Ports' concept, the toolkit uses an Integrated Port Management (IPM) framework comprising four key phases: planning, design, construction, and operations to introduce a more comprehensive approach that integrates social sustainability considerations. It provides practical guidance on incorporating environmental impact assessments, circular economy principles, waste management, effective ballast water management and more, into port planning and operations. The toolkit also emphasises the importance of stakeholder engagement and policy integration to ensure that sustainable practices are embedded at all stages of port development.

This is a valuable resource for policymakers, port authorities, and developers. Although specifically developed for the WIO region, learnings and recommendations can be transferred to other contexts and geographies.

### Guyana Mangrove-Seawall Engineering Guidance[175]

The Guyana Mangrove-Seawall Engineering guidance from Deltares and Conservation International supports the implementation of green-grey coastal infrastructure through the establishment of design standards that integrated mangrove restoration with engineered solutions like seawalls.

This is one of the few current examples of technical specifications and practical methodologies for designing combined mangrove-seawall structures. The guidelines emphasise site-specific adaptations, accounting for the local wave climate, sediment flow, and ecological conditions, which are critical for ensuring the effectiveness and sustainability of green-grey solutions. The design process outlined in the guide incorporates stakeholder engagement and multi-sectoral collaboration. The guidelines also establish protocols for evaluating the performance of green-grey infrastructure over time, allowing for iterative improvements and scaling up of successful strategies.

Mangrove seawall, Guyana (Source: Link, Photo by: Conservation International)

## Evolving guidance and standards

Engineers currently lack structured tools to help incorporate nature into engineering design processes or to identify entry points within existing policies and decision-making frameworks.

NPE requires deeper integration of ecological principles in engineering guidelines, yet ecologists and engineers often operate in separate professional spheres, using different languages, priorities, and methodologies. This communication gap is not effectively addressed by current technical guidelines.[176] At the same time, environmental professionals must better understand the practical constraints of engineering to co-develop scalable, workable solutions.

Most existing standards continue to default to traditional 'grey' infrastructure approaches, often favouring concrete-heavy solutions that overlook ecological considerations. This is especially true in sectors where engineered reliability is prioritised to safeguard communities and critical infrastructure. Although there is growing interest in green-grey approaches, where well-designed grey components can offer enhanced reliability under future climate conditions, comprehensive technical frameworks to support their design and implementation remain underdeveloped.[177]

A key limitation of current guidance is its tendency to address complex issues in isolation. In reality, challenges like biodiversity loss, water and food security, and climate change are deeply interconnected. When technical standards fail to reflect these systems-level relationships, solutions risk addressing one problem while exacerbating others. In addition, equity and justice considerations are often insufficiently incorporated into existing frameworks, despite their importance in shaping sustainable and inclusive outcomes.

**To advance NPE, the profession needs to develop comprehensive, cross-disciplinary guidance and standards informed by evidence from both practice and research.** Building on what already exists and working with other disciplines, engineers can implement the following practical actions immediately:

- Establish lifecycle-based frameworks that identify clear entry points for NPE approaches and solutions within engineering decision-making processes and existing policy structures.[178]
- Create complementary guidance for planning, designing, implementing, monitoring and maintaining NPE solutions. Examples include: engineering manuals of practice for nature-based infrastructure solutions, guidance on integrating natural capital assessment and ecosystem valuation into infrastructure development, and adaptation of carbon management frameworks into nature management frameworks specifically for engineers.
- Develop standardised methods to assess future risks and trade-offs, particularly regarding the climate-nature-health nexus. This requires sustained dialogue between industry, regulators and environmental experts to create guidance that effectively balances innovation with safety considerations.

## The role of research and innovation

Advancing NPE requires dedicated research and innovation that builds the evidence base while developing practical solutions to inform engineering practice.

Pilot projects form a strong foundation for empirical research. Long-term studies tracking the performance of pilots across sectors are essential for understanding how nature-positive solutions evolve over time and under changing climate conditions. Many promising pilots remain isolated experiments, with their valuable lessons failing to influence mainstream practice or policy frameworks. **For NPE to achieve transformative impact, we must move beyond isolated demonstrations to systematic knowledge transfer.**[179]

Local context remains critically important for successful interventions. Solutions must be adapted to specific ecosystems and communities, ensuring that Indigenous knowledge is integrated to enhance contextual understanding and solution development.[180]

Research and innovation will be key to the successful scaling and implementation of NPE in the long-term. Collaborative research initiatives that bring together diverse stakeholders – like the Collaboration for Environmental Mitigation & Nature Inclusive Design (CEMNID) Project – can help generate robust evidence and innovative approaches.[181]

Emerging innovations offer promising examples of solutions that are already supporting nature-based approaches to infrastructure, including seaweed binders, oyster-shell aggregates and other marine biobased materials,[182] and bacteria-based techniques to clean sediment contamination during port expansion or maintenance dredging, avoiding costly and risky excavation of hazardous materials.[183] Academic and investor support will be critical to ensure these kinds of solutions can continue to develop and scale.

Other areas that would benefit from further research include:

- the impact of infrastructure and other anthropogenic interventions on ocean health
- the use of technology to support marine spatial planning
- near real-time, open data sharing platforms to enhance ocean modelling accuracy
- the systematic measurement and monitoring of nature-positive approaches, and
- the climate-nature-health nexus effects

NPE innovation should also align with broader ocean science goals such as those in the UNESCO Ocean Decade. The emphasis must be on generating science that directly informs standards, best practices, and policies – creating a virtuous cycle where research fuels implementation, and implementation experience informs future research priorities. When science, policy, industry and communities come together and co-design processes, this ensures that research outputs are actionable and regulatory gaps are addressed effectively. Open innovation platforms and hackathons, such as those conducted by Ocean Twin,[184] foster collaborative problem-solving across disciplines.

## Pathway 3: Advocating and partnering to accelerate nature-positive action

The global 'Nature Positive' movement is gaining momentum, uniting diverse sectors under a shared mission to halt and reverse biodiversity loss and ecosystem degradation. Advocacy and partnerships play crucial roles in this transformation – bridging scientific knowledge, engineering practice, policy influence, and grassroots action.

**The scale and urgency of the challenge require an inclusive and coordinated response.** Several global initiatives across the private sector, civil society and academia demonstrate the power of partnerships in driving nature-positive outcomes.

- **BES-Net (Biodiversity and Ecosystem Services Network)**[185] is a capacity-sharing initiative managed by the United Nations Development Programme (UNDP) that helps bridge the science-policy-practice interface on biodiversity and ecosystem services.
- **The Nature Positive Initiative (NPI)**[186] is a global coalition launched in 2023 to drive alignment, clarity, and accountability around the Nature Positive global goal, i.e. halting and reversing biodiversity loss by 2030 and restoring nature by 2050.
- **Nature Positive Universities**[187] engages academia in promoting nature on campuses, in supply chains and within cities and communities.
- **Business for Nature**[188] unites businesses and NGOs to influence policies that support nature restoration.
- **The Partnership for Environment and Disaster Risk Reduction (PEDRR)**[189] promotes NbS for disaster risk reduction and climate resilience in line with the Sendai Framework for Disaster Risk Reduction.
- **Nature4Climate**[190] is a coalition that champions NbS for climate mitigation and adaptation.

The voice and contribution of engineers have largely been missing from the global debate on nature-positive approaches and from important convenings such as Biodiversity COP. Given their importance in shaping the infrastructure of the future, it is crucial that engineers are involved in this global movement if we are to achieve a nature-positive world. Engineers, with their credibility and technical expertise, must become key advocates in this shift, drawing decision makers' attention to what works, what should be avoided, and what to prioritise.

A window of opportunity now exists to establish an alliance of engineering actors to scale up NPE through targeted capacity building, coordinated advocacy, and the formation of global communities of practice. This will create a space for stakeholders across the global engineering community to come together to champion NPE and its safe implementation at scale.

# Nature-positive engineering guiding principles

The vision for NPE is to become a universal framework that applies across all engineering contexts, facilitating coordination among policymakers, investors, and industry stakeholders pursuing nature-positive outcomes.

Central to this framework are the NPE guiding principles, developed through an extensive literature review and expert consultation. These principles are the essential building blocks for implementing NPE. Together, they reflect both the philosophical and practical foundations needed to achieve a nature-positive world.

**Fostering a mutually enhancing Human-Nature relationship[191] –** Recognise that humans are part of nature itself[192] and that solutions must deliver benefits across environmental, social, and economic dimensions, requiring the collective involvement of multiple disciplines. Successful NPE creates a self-reinforcing cycle where ecological health improves human wellbeing, in turn strengthening community stewardship of natural systems. It moves beyond the false division of nature versus development, and recognises nature as an asset with inherent value.

**Taking a whole lifecycle approach to ecological impacts[193] –** Assess impacts on natural ecosystems across the full lifecycle and identify opportunities for positive interventions at every stage – including material sourcing, construction methods, and operations and decommissioning. Prioritise solutions that move beyond 'no harm' to actively enhance biodiversity. Where feasible, favour no-build or low-build options.[194]

**Delivering measurable nature improvements –** Establish clear, evidence-based metrics, supported by robust measurement and monitoring frameworks, and enhancing multiple dimensions of nature, including biodiversity, atmospheric and ocean metrics, and tracking these outcomes over time using methodologies based on common principles.

**Recognising interconnectedness across scales and timeframes –** Acknowledge that NPE interventions have complex, far-reaching effects that extend beyond project boundaries and interact with broader ecological and social dynamics. Consider that ecological creation, recovery and regeneration unfolds over time, design for both immediate functional enhancements and long-term ecological processes.[195]

**Co-developing solutions with local communities and Indigenous People[196] –** Ground solutions in principles of inclusivity, equity, and respect for diverse knowledge systems. Indigenous and local knowledge offer critical insights into ecosystem dynamics, sustainable practices, and culturally meaningful solutions. Successful implementation depends on ongoing care and management, which is most effectively provided by engaged local communities with direct stakes in ecosystem health.

**Designing multifunctional[197], regenerative systems[198] –** Adopt regenerative design practices that restore ecosystems and create circular systems where materials are reused, recycled, repurposed or safely disposed of. This involves responding to each location and context's unique features while ensuring benefits are equitably distributed across communities and contributing positively to planetary health beyond just local biodiversity.[199]

**Managing complex risks and trade-offs[200] –** Proactively identify and assess complex risks and potential tensions between engineering functionality, ecological enhancement, and equity. Develop frameworks to evaluate these trade-offs transparently, acknowledging that perfect solutions rarely exist. Balance immediate infrastructure needs against long-term ecosystem recovery while maintaining safety and functionality. Engage stakeholders in transparent discussions about risk tolerance and acceptable compromises.

**Addressing the climate-nature-health nexus through adaptive management[201] –** Acknowledge the reality of accelerating climate change and the need to consider combined climate-nature futures and their impact on both human health and natural ecosystems; build flexibility and adaptability in infrastructure and natural systems so they can withstand and adapt to changing conditions.

**Fostering interdisciplinary collaboration –** Bring together diverse forms of knowledge from engineering, ecology, social sciences, and other fields from project inception. Recognising that no single discipline possesses all the knowledge needed to design effective nature-positive solutions, use collaborative approaches that bridge traditional disciplinary boundaries.

**Anticipating and managing potential unintended consequences –** Recognise that well-intentioned interventions in complex ecosystems may trigger unexpected and potentially unsafe consequences. Understand the natural system, monitor and be prepared to course correct when nature responds in unanticipated ways to engineered solutions.

# Findings and recommendations

## Findings

This foresight review reveals eight key findings that frame both the challenge and opportunity of NPE:

**Engineers can be change agents in addressing the nature crisis.**

The accelerating nature crisis requires immediate action; every year of delay in adopting nature-positive approaches raises both the costs of intervention and the risk of irreversible ecological damage. As the principal designers and builders of infrastructure and the built environment, engineers directly shape how humanity interacts with natural systems. This gives them not only a profound responsibility but also a unique opportunity to lead the transition toward regenerative, nature-positive solutions through NPE practices.

**Nature-positive must also be people-positive.**

People are part of nature, not separate from it. NPE must deliberately integrate human safety and wellbeing with nature's wellbeing. This connection isn't automatic – it requires thoughtful design that delivers safer outcomes and social equity alongside environmental health. When communities thrive from nature's recovery, they become its strongest advocates, creating lasting stewardship relationships.

**Systemic barriers exist across policy, finance and technical capacity.**

Current policy frameworks, financing mechanisms, and technical standards still favour traditional 'grey' infrastructure over nature-positive alternatives, creating systemic barriers to NPE adoption. Fragmented regulations, siloed approaches, and short-term financial thinking misalign with nature's longer recovery timeframes, while both engineering education and current practice lack integration of the interdisciplinary knowledge, skills and competencies necessary for implementing nature-positive solutions.

**Promising approaches exist across all sectors.**

Innovative NPE solutions are already being implemented across coastal protection, ports and shipping, and renewable energy sectors. These approaches demonstrate the feasibility of integrating ecological considerations into infrastructure development and provide valuable templates for engineering within natural environments.

**NPE can accelerate nature-positive development.**

Future infrastructure development and urbanisation trends open the door to NPE and present timely opportunities for action. The task now is to enable and mobilise the engineering workforce to accelerate nature-positive change. NPE serves as a key implementation pathway for nature-positive infrastructure, embedding ecological considerations across the entire infrastructure lifecycle. In practice, NPE must address all drivers of biodiversity loss, including climate change, pollution, and resource consumption. A diverse range of existing approaches can support this vision and must now be embraced and scaled. Through greater clarity on what immediate, pragmatic actions can be taken, NPE can reshape human development to place both nature and society at the heart of design, fostering a more inclusive, equitable, and safer world where people and nature thrive together.

**A paradigm shift in engineering practice and education is needed.**

NPE requires a fundamental shift – from viewing nature as an expendable resource or an obstacle, to recognising it as a partner and ally. Nature positivity must become a core objective of engineering, alongside safety, efficiency, and functionality. This goes beyond sustainability's focus on "doing less harm" towards a proactive ethos of "doing more good." Achieving this will require transformation in both engineering practice and education, supported by changes in the regulatory systems within which engineers operate. Engineers must also play a leading role in developing the standards that enable NPE.

**Future solutions must consider a changing world.**

Designing resilient infrastructure that will function for decades requires planning for varied climate trajectories and ecological responses. Engineering must now incorporate adaptive, flexible solutions that balance environmental, social, and economic benefits, creating infrastructure that supports both natural systems and human communities. Achieving this calls for new 'toolkits' to better understand and manage complex risks and trade-offs.

**Robust measurement and interdisciplinary collaboration are key.**

Standardised frameworks and metrics, long-term measurement, and monitoring are needed to scale up implementation, incentivise investment, and demonstrate meaningful progress. Sustained monitoring over extended timeframes becomes particularly critical as nature-positive interventions often require years or decades to reach full effectiveness, necessitating commitment to measurement programmes that extend well beyond typical project delivery cycles. NPE approaches require interdisciplinary collaboration, bringing together engineers, ecologists, social scientists, economists and other specialists; solutions should be co-designed with project developers, local communities, and Indigenous People.

**Engineers must find their voice.**

A nature-positive transformation requires systemic and urgent collaboration from across sectors, disciplines and regions. Engineers must step up and actively participate in the global nature-positive movement, working with others to break down existing barriers. They can become powerful advocates for delivering a nature-positive world. Alongside other built environment professionals, engineers possess invaluable insights about what can realistically be achieved and how to safely accelerate implementation. To do this, technical expertise must be actively engaged upstream in policy development and decision-making forums, ensuring that technical knowledge informs regulatory frameworks and investment priorities.

## Recommendations

This foresight review makes ten recommendations for integrating NPE into engineering practice across three priority areas:

| Priority area | Action focus | Key recommendations |
|---|---|---|
| **Enabling environment** | Policy and regulations | 1. Leverage technology to identify synergistic planning and development opportunities |
| | | 2. Integrate nature-positive outcomes in permitting and procurement processes |
| | Finance | 3. Evolve natural capital risk assessment frameworks |
| **Building technical capacity** | Education and skills | 4. Develop and roll out an NPE knowledge module for engineering education and continued professional development |
| | Guidance and standards | 5. Create lifecycle guidance for safe and sustainable implementation of NPE |
| | | 6. Develop a climate-nature-health nexus 'future toolkit' for engineers |
| | Research and innovation | 7. Conduct comprehensive assessment of nature-positive metrics for ocean infrastructure |
| | | 8. Collate insights and evidence on NPE interventions including unintended consequences |
| **Advocacy and partnerships** | Advocacy and networks | 9. Establish an NPE global alliance and community of practice |
| | Advocacy and communications | 10. Advocate for safe nature-positive engineering practices across sectors and stakeholder groups |

## Enabling environment

### Policy and regulations

1. **Leverage technology to identify synergistic planning and development opportunities:** A comprehensive deep dive study should examine how cutting-edge technologies can enhance marine spatial planning and identify opportunities with blue economy agendas. This research should focus on how technology and data can support decision-making leveraging technologies such as integrated Geographic Information System (GIS) platforms, blockchain, satellite-based remote sensing, AI, and visualisation. Additionally, it should explore data sharing platforms and standardised protocols enabling collaboration across sectors and jurisdictions.
2. **Integrate nature-positive outcomes in permitting and procurement processes:** Government procurement processes for infrastructure should be fundamentally redesigned to establish biodiversity enhancement as a core requirement rather than an optional consideration. This should include mandatory evaluation criteria that reward proposals demonstrating measurable ecological improvements, standardised biodiversity metrics for comparing tenders, requirements for long-term monitoring and contract conditions that ensure nature-positive commitments are delivered throughout project implementation.

### Finance

3. **Evolve natural capital risk assessment frameworks:** Financial institutions and multilateral development banks should adopt standardised methodologies for assessing both nature-related risks and opportunities in infrastructure investments. Building upon the TNFD recommendations, these frameworks should extend to include greater integration of climate risks, specific considerations on infrastructure assets across their lifecycle, new science and data, and sector-specific metrics. This would help redirect capital flows to the development of nature-positive infrastructure while better accounting for long-term risks to asset value.

## Building technical capacity

### Education and skills

4. **Develop and roll out an NPE knowledge module for engineering education and continued professional development:** A knowledge module on NPE should be created for integration into undergraduate and postgraduate engineering curricula, and continued professional development. This module would leverage the substantial knowledge base compiled in this foresight review as core content, covering NPE principles and case studies and expanding the scope from ocean infrastructure to other sectors, e.g. cities, transport. The module should be designed with input from industry practitioners, academic institutions and ecological experts to ensure relevance to future employment markets. The roll out should prioritise geographies where technical capacity lags, with support from local educational systems and professional development bodies.

### Guidance and standards

5. **Create lifecycle guidance for safe and sustainable implementation of NPE:** A comprehensive framework should be developed that identifies clear entry points for NPE approaches and solutions within engineering decision-making processes and existing policy structures. Building on and referencing existing resources, this framework would help practitioners embed NPE principles throughout the project lifecycle, with sectoral versions created for different industries.
6. **Develop a climate-nature-health nexus 'future toolkit' for engineers:** Engineers need a new toolkit to navigate complex interconnections between climate change, biodiversity and human health in infrastructure development. This should incorporate foresight methodologies such as scenario planning to anticipate ecological tipping points and system risks for infrastructure performance, including forward modelling of NPE approaches at critical temperature thresholds of 1.5°C, 2°C, and beyond. The toolkit should be developed through collaboration with IPBES and IPCC experts, scientists and practitioners across sectors. This effort must bring together engineers, policymakers, local communities and Indigenous people, investors, academia, and civil society, breaking down disciplinary silos for holistic decision-making that integrates technical requirements with ecological knowledge and community perspectives.

**Research and innovation**

7. **Conduct a comprehensive assessment of nature-positive metrics for ocean infrastructure:** A systematic review should be commissioned to identify, evaluate and standardise metrics for measuring biodiversity improvements and ecosystem service gains from nature-positive coastal infrastructure. This work should address the critical shortfall in marine and coastal metrics, as current frameworks like the State of Nature Metrics predominantly focus on terrestrial ecosystems. A dedicated Measurement and Monitoring Task Force should be established comprising industry leaders already developing metrics, alongside academic researchers, policymakers and regulatory bodies to coordinate efforts and prevent fragmentation. This should include practical guidance on baseline establishment, data collection protocols and verification methods suitable for different stakeholder capabilities.

8. **Collate insights and evidence on NPE interventions:** A structured programme should collect and synthesise evidence from existing NPE case studies, focusing particularly on safety, performance-related outcomes, unintended consequences and examples of regenerative design that were underrepresented in the foresight review process. The NPE guiding principles should provide an assessment framework to evaluate these case studies, analysing how current practices align with aspirational NPE approaches. This effort should extend beyond marine infrastructure to include urban development, transport, and energy systems, building a comprehensive evidence base that highlights transferable lessons across sectors.

**Advocacy and partnerships**

9. **Establish an NPE global alliance and community of practice:** A global partnership of engineering organisations committed to championing safe nature-positive approaches should be created. This alliance would coordinate advocacy efforts, amplify engineering voices in biodiversity policy discussions, and convene a community of practice for knowledge exchange and collective action on NPE. The alliance should join existing global nature-positive initiatives, such as the Nature Positive Initiative, to represent engineers and contribute to international scientific assessments by IPBES and the IPCC.

10. **Advocate for safe nature-positive engineering practices across sectors and stakeholder groups:** As a new and important addition that brings the rigor and scale of engineering to existing nature positive initiatives, there is a need to increase the visibility of NPE to scale adoption by engaging with engineers to highlight nature as both a key risk and opportunity; focusing on regulatory frameworks and policy synergies for policymakers; emphasising risk reduction and return opportunities for investors; and highlighting connections between biodiversity and community wellbeing for the public. The campaign should deliberately frame nature-positive approaches as people-positive by showcasing projects that deliver integrated benefits across social equity, economic development and nature gains..

## Opportunities for Lloyd's Register Foundation

Lloyd's Register Foundation is uniquely positioned to catalyze change where others cannot. Of the recommendations made in this review, there are two that are unlikely to progress in the near-term without the Foundation's support due to a lack of business or regulatory drivers at time of writing.

Developing an NPE knowledge module for engineering education (Recommendation 4). The Foundation's most valuable role would be to act as a trusted convener, bringing together leading experts, universities, professional bodies, and training providers to co-create a knowledge module that embeds NPE principles into engineering education and professional development. Building on the substantial body of knowledge already generated through the foresight review, the Foundation could ensure that the module is not only technically sound, but also globally relevant, accessible, aligned with future skills needs, and by leveraging its international partnerships, the Foundation could help accelerate integration of NPE into curricula and professional standards worldwide

Collating insights and evidence on NPE interventions (Recommendation 8). This recommendation plays directly to the Foundation's strength as a trusted source of safety evidence and insight. The Foundation's role could be to convene and commission collaborations between academic, research, and practitioner communities to systematically gather and assess global evidence on how NPE principles are being implemented in practice. By enabling the curation of this evidence base and making it accessible, the Foundation could close critical knowledge gaps, provide clarity on what works, and enable decision-makers to act with confidence.

Additionally, the Foundation is in a position to influence the implementation of all recommendations within this review, using its independence and evidence-based approach to drive wider uptake of nature-positive engineering.

# Annexes

# Annex 1 – Acknowledgements

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- **Rio de Janeiro:** Climate Champions Team; Governo do Estado de Rio de Janeiro
- **Singapore:** Singapore Green Finance Centre at Singapore Management University; Conservation International

# Annex 2 – Glossary

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| **Biodiversity[202]:** | The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes genetic variations in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems. |
| **Building with Nature (BwN)[203]:** | An approach to engineering that integrates natural materials, processes, and dynamics into infrastructure design. It aims to address climate risks like flooding and sea-level rise while delivering co-benefits for ecosystems and society. |
| **Circular economy[204]:** | A model of production and consumption which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the lifecycle of products is extended. |
| **Cradle-to-cradle[205]:** | The design and production of products of all types in such a way that at the end of their life, they can be truly recycled (upcycled), imitating nature's cycle with everything either recycled or returned to the earth. |
| **Ecological engineering[206]:** | The design, construction, and management of ecosystems to benefit both humans and nature, integrating engineering principles with ecological knowledge for sustainable solutions. It is engineering in the sense that it involves the design of this natural environment using quantitative approaches and a basis in science; it is technology with the primary tool being self-designing ecosystems. |
| **Ecosystem-based adaptation[207]:** | The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change. |
| **Ecosystem services[208]:** | The benefits that nature can provide to people . They are divided into four categories: provisioning, regulating, supporting, and cultural services. |

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| **Ecosystem-based disaster risk reduction or Eco-DRR[209]:** | The use of ecosystem-based approaches alongside disaster risk reduction strategies to enhance disaster prevention measures, minimise impacts on communities and ecosystems, and assist in recovery efforts. |
| **Engineering with Nature (EWN)[210]:** | The intentional alignment of natural and engineering processes to efficiently and effectively deliver economic, ecological, and social benefits through collaboration. EWN advances infrastructure solutions that, in addition to fulfilling engineering objectives, also generate economic, ecological, and social benefits. |
| **Mitigation and Conservation Hierarchy[211]:** | A framework that extends the principles of the four-step Mitigation Hierarchy for addressing the impacts of development on biodiversity: refrain, reduce, restore, and renew, to provide a framework for all sectors of society to contribute to global biodiversity goals. |
| **Natural capital[212]:** | The stock of renewable and non-renewable natural resources such as plants, animals, air, water, soils, and minerals that combine to yield a flow of benefits to people. |
| **Natural infrastructure[213]:** | Infrastructure that uses natural processes and ecosystem services to support engineering objectives, such as reducing flood damages or securing safe and ample water supplies. |
| **Nature[214]:** | Refers to the natural world with an emphasis on its living components. Within the context of Western science, it includes categories such as biodiversity, ecosystems (both structure and functioning), evolution, the biosphere, humankind's shared evolutionary heritage, and biocultural diversity. Within the context of other knowledge systems, it includes categories such as Mother Earth and systems of life, and it is often viewed as inextricably linked to humans, not as a separate entity. |

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| **Nature-based infrastructure[215]:** | Nature-based infrastructure is the strategic use of natural and semi-natural ecosystems to provide essential infrastructure services that support human communities and economic activities. This approach leverages the inherent capabilities of healthy ecosystems to deliver functions traditionally provided by built infrastructure, such as water filtration, flood protection, and coastal defense, while simultaneously maintaining biodiversity and ecosystem health as foundational requirements for long-term service delivery. |
| **Nature-based solutions[216]:** | Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services, resilience and biodiversity benefits. |
| **Nature-inclusive design (NID)[217]:** | Measures that are integrated into or added to the design of [offshore wind] infrastructures to increase suitable habitat for native species (or communities) whose natural habitat has been degraded. |
| **Nature-positive infrastructure[218]:** | A nature-positive approach that puts nature and biodiversity gain at the heart of decision making and design. It goes beyond reducing and mitigating negative impacts on nature as it is a proactive and restorative approach focused on conservation, regeneration and growth. |
| **No-build / Low-build[219]:** | Practical solutions for reusing or maximising the existing infrastructure asset base, offering benefits to protect, conserve, restore, sustainably use and manage ecosystems while supporting human and environmental benefits. |
| **Planetary boundaries[220]:** | The safe limits for human pressure on the nine critical processes which together maintain a stable and resilient Earth. These nine boundaries are climate change; biosphere integrity; land-system change; freshwater change; biogeochemical flows; ocean acidification; atmospheric aerosol loading; stratospheric ozone depletion; and novel entities. |

# Annex 3 – Measurement and monitoring technologies

- **eDNA**[221] analysis is a non-invasive method for detecting marine species by identifying genetic traces they leave in the water, such as skin cells or waste. By analysing water samples, scientists can determine which species are present without needing to capture or observe them directly, making it an efficient tool for monitoring marine biodiversity and detecting invasive species with minimal disturbance.
- **AI-powered drones and video analysis**[222] enable efficient, near real-time monitoring of marine wildlife such as seabirds, turtles, and marine mammals. Algorithms automatically detect and classify species from aerial footage based on visual patterns, reducing the need for manual identification. This allows rapid ecosystem health assessments, habitat mapping, and informed decision-making for marine planning and conservation.
- **Autonomous underwater vehicles (AUVs)**[223] gather in-situ data on fish, benthic species, and environmental variables, enabling high-resolution monitoring of marine biodiversity, habitat condition, and ecological change over time.
- **Satellite-based earth observation methods**[224] like multispectral imaging, ocean color sensing, SAR, and sea surface temperature mapping enable large-scale monitoring of marine biodiversity. They can detect habitat health, phytoplankton levels, algal blooms, and temperature changes, providing vital data for tracking ecosystem dynamics and species distribution.
- **Digital twins**[225] model marine ecosystem conditions by creating digital representations of coastal and ocean environments and infrastructure. These models simulate intervention effects over time, enabling predictive analysis and informed decision-making. Many digital twins also include advanced visualisation tools to engage stakeholders effectively.[226]
- **LiDAR (Light Detection and Ranging)** is a remote sensing technology that uses laser pulses to measure distances and create detailed 3D maps. In marine monitoring, LiDAR can penetrate shallow water to map seafloor topography, monitor coastal erosion, track changes in coral reefs, and assess marine habitat structure from aircraft or boats.

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