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Staged implementation prioritization system for maximizing NBS benefits

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Abstract

Urban areas face increasing challenges from climate change, including flooding, heat stress, and environmental degradation. To address these, Nature-Based Solutions (NBS) offer sustainable approaches, integrating ecological and engineering principles to enhance resilience. However, the implementation of NBS often leads to lock-in effects, where suboptimal initial decisions limit future flexibility. This study presents a prioritization system for NBS implementation, ensuring maximum long-term benefits while avoiding costly redesigns. The proposed framework is informed by real-world implementations from the **Interreg Central Baltic MUSTBE (2023)** and **LIFE LATESTAdapt (2022)** projects, incorporating multi-objective performance indicators (MOPI) and cost-benefit analysis (CBA). The results highlight that early-stage decision-making significantly influences the long-term viability and economic efficiency of NBS investments. Case studies demonstrate how flexible design choices and adaptive planning approaches lead to more cost-effective, multi-functional solutions. By integrating environmental, social, and economic considerations, this research provides a practical guide for urban planners and policymakers to optimize NBS strategies while ensuring long-term sustainability.

Highlights

- Municipalities lack the knowledge and tools to develop budgets for NBS
- Optimization of the multi-objective NBS in the initial phase has an important role for the early-stage manifestation of the benefits parameters
- NBS require significant initial investment for through planning and alternatives comparison

Introduction

Municipalities have a political interest to enhance urban green spaces to mitigate adverse climate change effects, including flooding, drought, heat waves, and associated health risks. Achieving optimal, multifunctional solutions requires early collaboration among specialists from various fields. Nature-based solutions (NBS) are increasingly recognized for addressing environmental challenges by leveraging natural processes in urbanized areas. While the number of NBS projects globally is increasing, inconsistent definitions and reporting standards complicate precise estimates. However, organizations and initiatives, such as IUCN, European Union and the RECONECT project have developed standards and tools to guide NBS design and implementation. The Global Standard for NBS (IUCN, 2020), in particular, provides a framework with clear criteria for assessment and implementation. The NBS co-creation tool developed in RECONECT (Dushkova & Kuhlicke, 2024) emphasizes the participatory, iterative nature of co-creating NBS, particularly for disaster risk reduction and stakeholder engagement. The Think Nature handbook (European Union, 2019) focuses on knowledge dissemination, addressing stakeholder needs, and providing guidance on implementation, monitoring, and policy integration. Together, these frameworks contribute to a comprehensive understanding, integrating standards, methodologies, and practical applications across various contexts. On the other hand, the frameworks mainly highlight specific single-purpose key performance indicators (KPI) that should be used as a basis for planning NBSs. Focusing separately for each KPI in the planning and designing process can lead to lock-in effects. Lock-in effects are situations where initial decisions create strong incentives to continue on a particular path, even if more efficient alternatives become available later (Drechsler & Wätzold, 2020). However, in the cities we have limited space for implementing NBSs and in this case it is important to understand how it is possible to optimize solution for multiple KPIs at the same location. This highlights the need of understanding how to design NBSs based on multi-objective performance indicators (MOPI).

This research analyses aspects of the practical implementation of the NBS in line with the frameworks, based on pilot solutions of Interreg CB MUSTBE (2023) and LIFE LATESTAdapt (2022) projects in North Europe region

Methodology

The methodology for implementing NBS followed a structured, multi-step approach (Figure 1). First, municipalities selected pilot areas based on development plans, budget availability, and potential for improving green spaces. Next, KPIs were identified in collaboration with local governments, focusing on environmental and social benefits such as flood risk reduction, biodiversity, and public well-being.

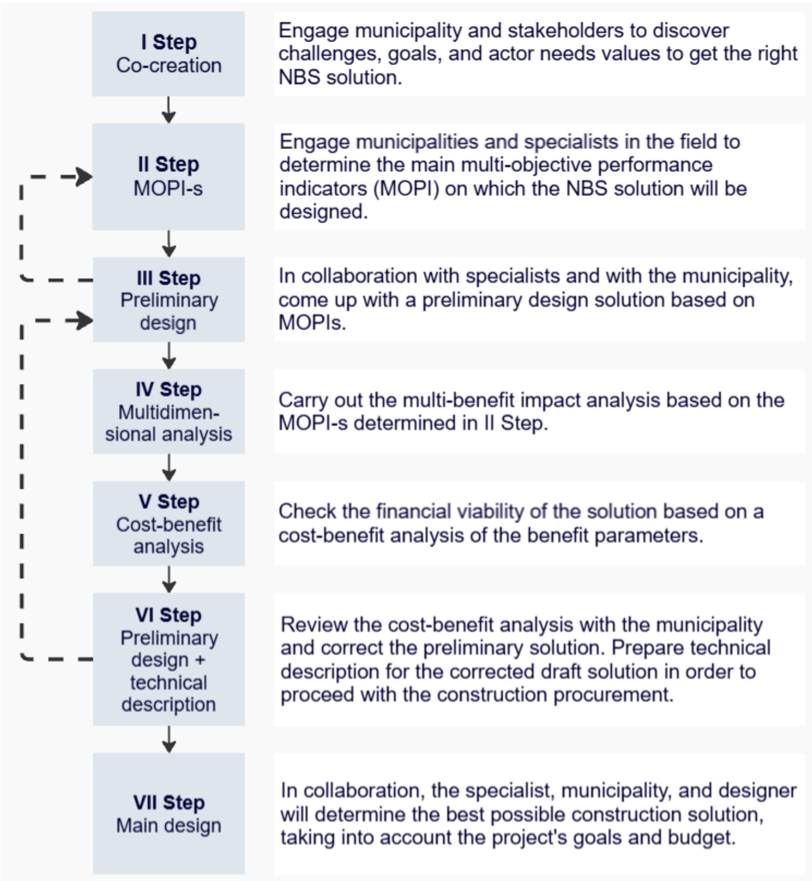


Figure 1. This is a seven-step process diagram for creating an NBS, which begins with planning stage and ends with the work project stage.

These KPIs informed the development of MOPIs to ensure the NBS provided both primary and co-benefits. The goal of MOPI is to find the interoperability of solutions designed for multiple KPIs in the same location. This in turn allows for maximum use of the land area used for the NBS. According to that, a preliminary NBS design is created based on site characteristics, land use, and MOPIs, with iterative adjustments as needed. A multidimensional benefit analysis assessed the effectiveness of the solutions based on four key parameters: flood risk reduction, water quality improvement, urban heat mitigation, and public well-being. Also, a Cost-Benefit Analysis (CBA) was conducted using Net Present Value (NPV) and Benefit-Cost Ratio (BCR) calculations over a 30-year lifecycle, confirming the financial viability of the solutions. Municipalities conducted design procurement according to national regulations, ensuring cost-efficient selection of design contractors. The final design phase involved expert reviews and revisions before completing technical documentation, material lists, and budget estimates. This structured methodology ensured that NBS implementations were both environmentally and economically sustainable.

Case study

The structured methodology for developing NBS has been informed by 12 pilot sites from the different international cooperation projects among 4 countries in the Baltic-Nordic region. Herein the results of the multidimensional and cost-benefit analysis, along with a more detailed overview of the engineering experience of 4 pilot sites is presented.

Results and discussion

Results

The main focus of these projects is to reduce flood risks and improve the quality of water entering the Baltic Sea. Both projects involved representatives of various parties, like municipalities, NGOs and academies. The engineering experiences are presented for Estonian pilot areas: Viimsi (MUSTBE), Tallinn (MUSTBE), Viimsi (LIFE LATESTAdapt), and Võru (LIFE LATESTAdapt). The four pilot areas faced several recurring challenges that led to redesign: late baseline surveys, legacy design practices, budget limits and poor communication. The main challenges in the design were late baseline surveys and legacy design practices. Viimsi (LIFE LATESTAdapt) pilot area presented the most challenges. Table 1 presents the main challenges encountered during the design process across all four pilot areas.

Table 1. The main challenges that caused redesign of NBS design

Pilot	Late baseline surveys	Legacy design practices	Budget limits	Poor communication
Viimsi (MUSTBE)		X	X	
Tallinn (MUSTBE)	X	X		
Viimsi (LIFE LATESTAdapt)	X	X		X
Võru (LIFE LATESTAdapt)	X		X	

For better understanding and illustration of the process description, the design process for Viimsi pilot site solution is presented in the figure 2. Figure 2. shows the design journey of the Viimsi pilot area from the existing situation to the solution presented in the main design.

The original design of the pond and park system proposed for the Viimsi green area did not account for water quality enhancement or adaptive flow regulation in response to variable weather conditions such as flooding or drought. Upon review, the design was revised to incorporate NBS aimed at improving stormwater quality and regulating flow dynamics.

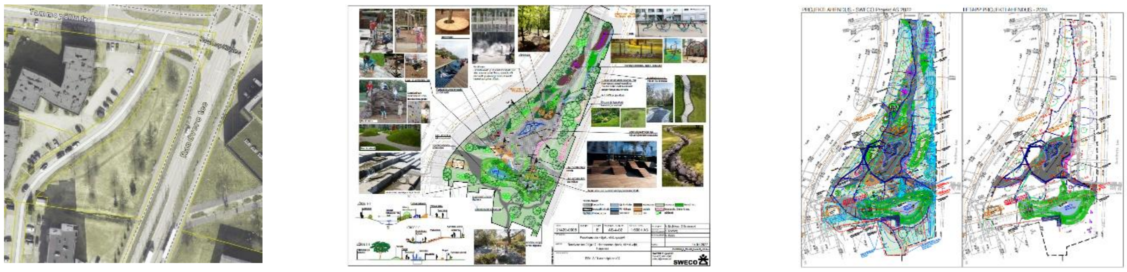
Key modifications included reversing the slope of the pond bottom to direct sediment accumulation away from the outflow, and integrating a sedimentation zone at the inflow point. Additionally, aquatic vegetation was introduced to enhance the pond's natural purification processes—for instance, by binding chloride particles present in stormwater.

To support dynamic flow management, the redesigned system includes sensors for real-time monitoring of water quality and discharge rates. These are integrated into Viimsi municipality's web-based control platform, VAAL, enabling automated and remote system operation tailored to fluctuating weather conditions.

Following the redesign, a construction budget was prepared. It became evident that the available funding did not support full implementation of the proposed solution in a single phase. As a result, the project was divided into stages. While multi-criteria and cost–benefit analyses confirmed the overall feasibility and profitability of the solution, the staged construction approach delays the realization of benefits across all target dimensions. The first phase will focus on components that enhance water quality and streamflow regulation. Subsequent phases will address goals related to biodiversity enhancement and social well-being.

Figure 2. An example of a pilot area design process.

MUSTBE - VIIMSI		
a) Existing situation in the pilot area	**b) The first planned solution, designed according to stakeholders and municipality priorities**	**c) Amended solution, after analysing the cost-calculation and municipality construction budget for the implementation**



For conclusion all four pilot projects demonstrate the importance of integrating a multi-objective approach in urban stormwater management. Specifically, they show that objectives such as flood mitigation, water quality improvement, ecological enhancement, and social well-being must be addressed in tandem within a single, cohesive design.
These case studies highlight the value of adopting a MOPI framework from the earliest planning stages. Implementing MOPI enables planners and designers to evaluate and balance the diverse goals of NBS more effectively, leading to solutions that are not only technically and environmentally sound, but also economically and socially sustainable.

Discussion

NBS offer long-term economic benefits over conventional grey infrastructure but require significant upfront investment. Their higher costs stem from integrating multiple components to serve diverse stakeholders, whereas grey infrastructure is simpler, solving single problems efficiently. However, municipalities struggle with funding due to inadequate budgeting knowledge, making phased implementation necessary.
There are several gaps in the design and construction process of NBS:

- Challenges of phased implementation
- Budgeting and competency gaps
- Design and regulatory constraints

Phased NBS deployment delays full benefits, reducing overall efficiency. The synergy of NBS components is crucial, and incomplete solutions may underperform, necessitating costly adjustments. This fragmentation weakens the intended environmental, social, and economic impact. Municipalities often miscalculate NBS costs, leading to underfunding and incomplete implementations.

Conclusions and future work

To optimise NBS adoption, municipalities need improved budget frameworks that reflect their multifaceted benefits. Collaboration between civil engineers and land improvement specialists should be strengthened, and regulatory standards reassessed to prevent redundant designs. Addressing these gaps will enhance the financial, environmental, and societal efficiency of NBS.

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