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The Nature Smart Cities business model: a rapid decision-support and scenario analysis tool to reveal the multi-benefits of green infrastructure investments

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Abstract

Incorporating natural spaces within urban areas has been shown to have multiple benefits. However, despite greening and adaptation strategies at different levels of government, progress remains slow with a lack of easy to use and comprehensive tools identified as key to overcoming this. This paper presents a co-designed tool with academic and local authority partners to demonstrate the ecosystem service benefits of small-scale urban green infrastructure projects. Through the tool, users can readily assess the impact of green infrastructure investments on the delivery of a selection of ecosystem services in the early stages of a project. Furthermore, the tool provides a standardised assessment of cultural ecosystem services' contributions, as well as offering a method to score spatial designs on the impact on habitat for biodiversity. Use of the tool is demonstrated using a pilot study in Kapelle, the Netherlands. The results set out an overview of the impacts of the spatial design on estimated ecosystem service delivery. They also show the tool's potential to add value in early project stages and as a planning and design tool, helping to maximise the benefits that can be achieved through green infrastructure design. Complementing these arguments with ball-park estimations on green infrastructure costs, the Nature Smart Cities Business Model aims to offer public sector officers the means to create a business case for green infrastructure measures, facilitating the translation from strategies to actual plans, thus benefitting green infrastructure implementation in the public realm.

Introduction

The incorporation of natural areas in urban and densely populated areas is increasingly recognised for its multiple environmental and social benefits (Carter et al., 2015; Mell, 2017), for example mitigating the impacts of surface flooding, reducing urban heat island effects, and increasing social cohesion among residents. Green infrastructure (GI) has the potential to deliver (re-)integration of (semi-)natural elements to create healthier, more climate-resilient, and enjoyable areas for urban residents (Pauleit et al., 2017), as well as raising awareness of the natural approach with both public and practitioners. Increasingly, (retro)fitting natural elements in populated environments provides a credible approach for urban planners to anticipate and mitigate inimical consequences (Bayulken et al., 2021). Interest in GI among with policy makers has increased in the last decade (Babí Almenar et al., 2021), with GI acknowledged through strategies at different levels of decision making (e.g., EU Strategy on Green infrastructure (supranational level), National strategy for Pollinators (Belgium – national level), Flanders' building shift (regional level). Nevertheless, implementation of GI and ecosystem services in local authorities' practice is still believed to be challenging and slow ((Back & Collins, 2022; Bowen & Lynch, 2017; Matthews et al., 2015; Roe & Mell, 2013). Research has uncovered a significant gap within (local) authorities between the strategic vision and the operational implementation dimension, not fully committing to policies' high-level goals, objectives, and ambitions (Back & Collins, 2022; Bush, 2020; Raynor et al., 2017).

The origins of this hampered implementation are discussed intensively in GI and nature-based solutions (NBS) literature. Viti et al. (2022) describe the perception of developers, that high(er) costs of operationalization and maintenance are a key barrier for widespread NBS application. Generally, the most cited barriers are indeed resource related: a lack of funding, and maintenance requirements (Li et al., 2020), but also the uncertainty or difficulty in measuring costs and benefits (Reu Junqueira et al., 2021). Further barriers or challenges include a lack of knowledge or expertise, unfavorable perceptions about GI, reluctance to change established practices, and institutional path dependence and siloes (Back & Collins, 2022; Dhakal & Chevalier, 2017; Matthews et al., 2015; O'Donnell et al., 2017; Voskamp et al., 2021). GI/NBS knowledge and evidence gathering, and efficient dissemination, could contribute to overcoming many of these barriers. One of the main gaps however remains if and how this knowledge is used in practice, at the local spatial planning level. Overcoming the GI implementation gap depends on the size of municipalities as well; smaller municipalities often have less capacity and perceive knowledge deficiencies, while larger municipalities are more likely to struggle with convincing developers (Back & Collins, 2022; Van Oijstaeijen et al., 2022). Thus, local capacity drives the perception of knowledge barriers. Adem Esmail et al. (2022) found that scientific literature is barely influencing the uptake of greening practices in spatial planning. Moreover, current local plans lack applications of the ecosystem services (ES) concept (Cortinovis & Geneletti, 2018). This finding is endorsed by previous literature identifying knowledge gaps between science and policy as a determining factor in the hampering NBS uptake (Bayulken et al., 2021). Narrowing the gap between scientific insights and local authorities' practice would benefit (especially for smaller municipalities) a transition towards more informed decision-making processes regarding greening practices.

From an academic perspective, interest in (urban) ecosystem service generation as a concept to be integrated in urban planning is receiving more attention (Haaland & van den Bosch, 2015). The growing body of evidence on the multi-functionality of (semi-)natural elements in built environments (especially in Europe) founds this statement (Chatzimentor et al., 2020). Research by Dick et al. (2018) with 27 ES/GI case studies revealed that the main benefit of ES research lies in knowledge accumulation, closely followed by directly applicable methods and tools to bridge between science and the development and implementation of decision making, management and planning. Integrating ES research in decision-support tools is a means to facilitate informed decision-making practices at the local scale, and the potential of this integration lies in the high potential of replication and upscaling (Longato et al., 2021). Comprehensive valuation mechanisms have been recommended (Di Marino et al., 2019; Ershad Sarabi et al., 2019) to assist local authorities (LAs) to increase support for GI implementation by evidencing the multiple GI benefits (Bowen & Lynch, 2017; O'Donnell et al., 2017) without additional local capacity requirements. A systematic review by Song et al. (2018) highlighted the need for comprehensive cost and benefit accounting methods, contributing to the inclusion of economic assessments into decision making. Currently, the largest added value that lies in GI/NBS – its multifunctionality – is generally disregarded, since GI projects are often implemented for single-purposes. The mainstreaming of comprehensive valuations for greening practices potentially reinforces the argument for the green option. In a more comprehensive approach, the wide range of co-benefits can be considered, strengthening the investment case for GI approaches. Expectedly, value revelation will contribute to facilitate funding issues.

This research responds to the call for practical applications and policy-science evidence for ES integration (Rozas-Vásquez et al., 2019). Hansen et al. (2019) identified a lack of application-oriented frameworks or decision-support tools at a local authority's disposal to mainstream the concepts of GI/ES/NBS in their planning practices. In recent years, interest in such tools is clearly increasing from an academic point of view, with more decision-support tools emerging serving a wide range of purposes (Van Oijstaeijen et al., 2020; Voskamp et al., 2021). They range in complexity from intuitive textual guidelines to complex hydrological or ecological modelling tools. However, it was found that many of these free-to-use tools are currently not used by local municipalities, because they seem too complicated, because they are just not known about, or because they don't provide comprehensive results across a range of ES (Back & Collins, 2022). Back and Collins (2022) conducted research with local authorities to find three key principles for uptake of these tools: useability, comprehensiveness, and credibility. Since the starting point for this research is the integration and mainstreaming of scientific knowledge and evidence in local decision making, a strong emphasis is put on these three key principles.

In the Nature Smart Cities project, a transdisciplinary approach to knowledge integration and applicable monetary valuation practices was adopted. Across the consortium of eight city partners and three academic partners, the science-policy interface was fundamental to the outcome of the project. By tying actual GI pilot investments to academically supported valuation and financing applications, collaboration across disciplines was stimulated in all steps of the spatial planning process. Fostering this collaboration and building on the evidence collected from real-life examples led to a detailed insight into the bottlenecks of GI implementation at the local level, as well as current shortcomings in academic approaches to ES knowledge integration and application. This project therefore focuses on the nexus between gaps in ecosystem services knowledge use and application in spatial planning and decision making, and the integration of business models to facilitate this. With this introduction of the Nature Smart Cities Business Model (NSC-BM), we contribute to raising capacity and aim to provide local authorities with the means to incorporate informed GI decision making practices by offering a comprehensive estimation of costs and benefits through ecosystem service valuation. Business models in the context of municipal authorities can be seen as the further elaboration of municipal strategic plans into actionable project ideas. The role of a business model for GI would be to guide the transition from strategic vision into actions. The Nature Smart Cities business model therefore helps to perform systematically an indicative comparative scenario analysis, especially relevant in early project planning and the design phases. This contributes to bringing a plan into practice on the project scale, while monitoring and further developing progress towards municipal strategic objectives. In what follows, the NSC-BM is first presented methodologically and secondly demonstrated through a case study. Further, the term “green infrastructure” is used as an encompassing application of ES and NBS.

Overview of the Nature Smart Cities Business Model (NSC-BM)

1. Development of the NSC-BM

A key element in every step of the development, displayed in figure 1, is close cooperation between academia and practice. This emphasis in itself explains the successful completion of the project, delivering seven GI pilot investments and the NSC-BM which is introduced in this research paper.

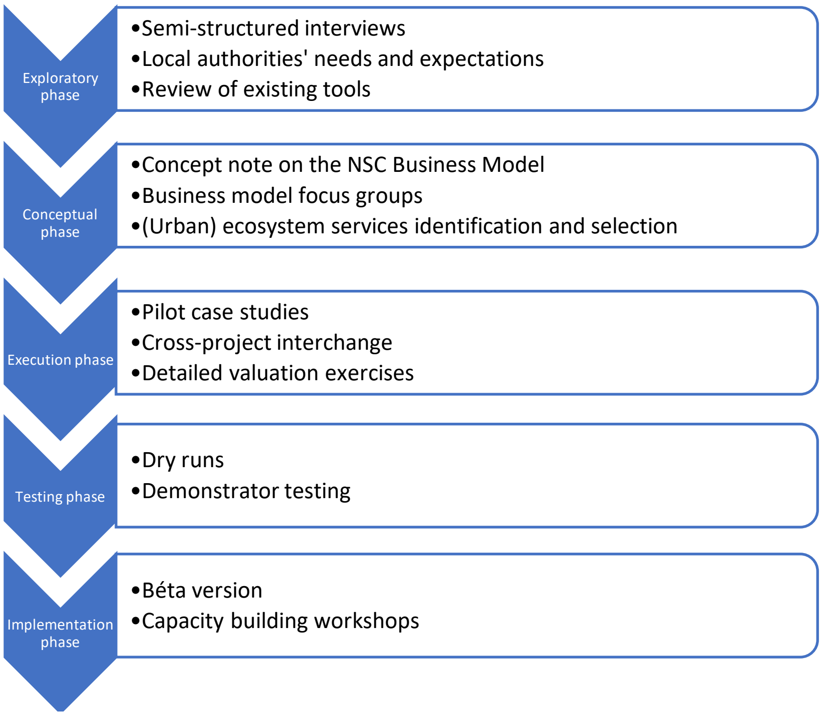


Figure 1: Overview of cascading phases in the development of the Nature Smart Cities business model

In the exploratory phase, the focus lay in exploring the state-of-the-art in academic literature and in identifying gaps and barriers in current practices. Within the NSC consortium, city partners’ needs and expectations were established through consultation. Alongside this, semi-structured interviews led to a ranking of priorities in municipal GI implementation (Back & Collins, 2021). Through a literature review of current decision-support tools and their practices (Van Oijstaeijen et al., 2020), a thorough understanding of shortcomings on the academic side was acquired. Both parts are elementary in the subsequent phase of conceptually defining the NSC-BM strategy. A concept note was prepared and was the subject of three (online) focus groups with the NSC consortium during partner meetings in October

2019, April 2020, and October 2020. While aligning the interests of city partners, the academic partners identified and selected ES to be included in the assessment with an emphasis on urban applicability (Bolund & Hunhammar, 1999). This way, the result is tailored for local officers to facilitate building a case for small-scale green interventions, providing arguments both in terms of ecosystem services and also tied to cost indications. After careful analysis of quantification methods for the selected ES, the academic partners conducted fieldwork on specific pilot cases to capture the extent of ES delivery. By comparing the results of these specific measurements with standardized and easily replicable valuation methods, the protocols for ES quantification and monetization were concretized. This phase was subject to cross-project interchange, building further on the existing knowledge base; in November 2020 an exchange event with the interreg2seas Cool Towns (www.cooltowns.eu) project took place, while the values database was also informed through collaboration with the IGNITION-project. An external contractor was recruited to program and automate the business model flow in MS Excel Visual Basic for Application (VBA).

Starting in July 2021, the first working version was subjected to several dry runs on actual GI cases by independent researcher Phil Back. After initial adjustments and bug fixes, the official demonstrator testing was initiated, running from September 2021 until November 2021. In this exercise eight demonstrator tests were carried out to prove the effective working of the NSC-BM and to identify areas where modification might be needed. Test sites were recruited through an open call, resulting in sites in the UK, the Netherlands and Belgium covering a range of GI projects. The demonstrator testing led to an extensive report of 309 comments, errata, feedback, recommendations, and suggestions (Back, 2021). All these were classified by the researcher in one of four groups: 'must do', 'should do', 'could do', and 'won't do', indicating their importance. Further, insight was gained into the relevance of the tool by subjecting the participants to a test against key criteria of usability, comprehensiveness, and credibility/clarity (Back, 2021). After careful revision, a beta version of the tool was launched internally. In February 2022, the project partners held a pilot testing retreat, in which all city partners were handed the toolkit and instructed to input their GI projects under the supervision of academic partners. Bug fixes and stability issues were addressed afterwards, preceding the public presentation of the tool through the capacity building programme. During two series of three workshops (March-April, June 2022), local authority officers in the UK, the Netherlands and Belgium were introduced to the tool. The first (online) series consisted of a general conceptual introduction of ecosystem services valuation, its relevance and how the tool narrows the existing ES knowledge and integration gap. Complementary to this theoretical approach, the second capacity building workshop series provided local authorities with the opportunity to be at the controls of the NSC-BM themselves. Serving as an important validating part of the project, participants were urged to share feedback and comments to better meet local officers' demands. A total of 266 individuals across 133 local authorities took part in the capacity building programme. Eventually, after processing the feedback from the capacity building programme, the Nature Smart Cities Business Model was officially launched at the Nature Smart Cities closing conference on September 28th, 2022.

2. Pillars of the NSC-BM

a. Co-creation and co-design

Earlier research has identified that the specific requirements of LAs are generally insufficiently addressed in existing GI tools (Van Oijstaeijen et al., 2020), contributing to the finding that very few LAs know of and make use of these decision-support tools. Therefore, the focus of attention in the entire process of developing the NSC-BM was the involvement of LAs, specifically targeting the tool's employability at the local scale.

b. Accessible multi-criteria decision analysis (MCDA)

The tool offers the base of a MCDA, combined with economic cost and benefit assessment. According to Langemeyer et al. (2016), a MCDA is a multi-step process that provides structure and formalizes decision-making processes transparently and consistently. In that respect, the NSC-BM aims to do this by integrating and standardizing an approach to adopt ES assessments in early-stage greening projects in urbanized environments. As a continuously evolving field in academia, the inclusion of the concept of (urban) ecosystem services allows for the tool to accommodate future scientific advancements. Furthermore, the EU encourages embedding the ES concept in decision-making, mainstreaming it through its own policies (Bouwma et al., 2018).

c. Green-grey-hybrid scenario analysis

Lack of expertise, know-how and capacity impedes evaluating the benefits of different approaches in early project stages. Tailored for small-scale and well-defined (urbanized) project areas, the NSC-BM serves to estimate how green, grey, and hybrid solutions impact ES generation on a scenario basis. Implementing the tool therefore helps to explore trade-offs that result from different spatial interpretations and to adapt or improve the project plans, which might facilitate securing appropriate (political) impetus or funding.

d. Multi-level value attribution

The benefit valuation method of the NSC-BM follows the reasoning offered by Kettunen (2009). The valuation pyramid (figure 2) illustrates how the full range of ES can be described largely in qualitative terms, a smaller subset of those can be quantitatively assessed, while only a fraction can be monetized.

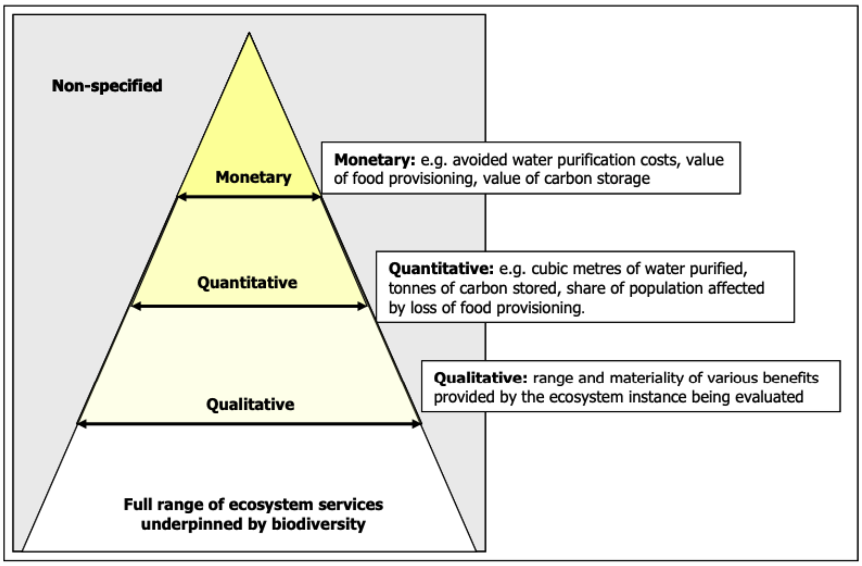


Figure 2: the valuation pyramid by Kettunen et al. (2009)

This flow of evidence is continued in the tool. While some ES can be monetized, the tool acknowledges the value plurality that is attached to urban GI by different stakeholders by combining qualitative, quantitative, and monetary evidence (Langemeyer et al., 2016; Spangenberg et al., 2015). However, the importance of acknowledging these different value dimensions in public decision-making is emphasized throughout the tool, and the evidence flow that can be obtained follows the reasoning of the valuation pyramid.

3. Nature Smart Cities Business Model flow

The tool is intended to be used by public sector officers and practitioners exploring the multi-benefits of greening measures across various land-use scenarios, specifically in early project stages to increase awareness of the full range of ES values (Cortinovis & Geneletti, 2018). The tool is pre-programmed as an automated Excel tool, estimating ES impacts and infrastructure-related costs based on a land use typology. In the first steps, users are expected to input the information about their greening projects and the project area. As described before, the NSC-BM offers the basis for a multi-criteria decision analysis (MCDA), with ecosystem services evidence as decision criteria. The outcome of the NSC-BM is a graphically supported and easily interpretable factsheet, where alternatives are set against each other for their decision criteria using pairwise comparison (Langemeyer et al., 2016). The flow of the NSC-BM is visualised in figure 3. The boxes in white depict the main steps or worksheets in the tool, while the boxes in grey represent worksheets that appear conditionally of the statements in the diamonds. The selection of the criteria (i.e., the ecosystem services to be included in the assessment) is the starting point for every application. Depending on the stakeholders involved, the user determines which ecosystem services are most relevant for this specific case and for the decision-making process. Further, the user's green infrastructure case is estimated using ball-park figures and simplifying assumptions.

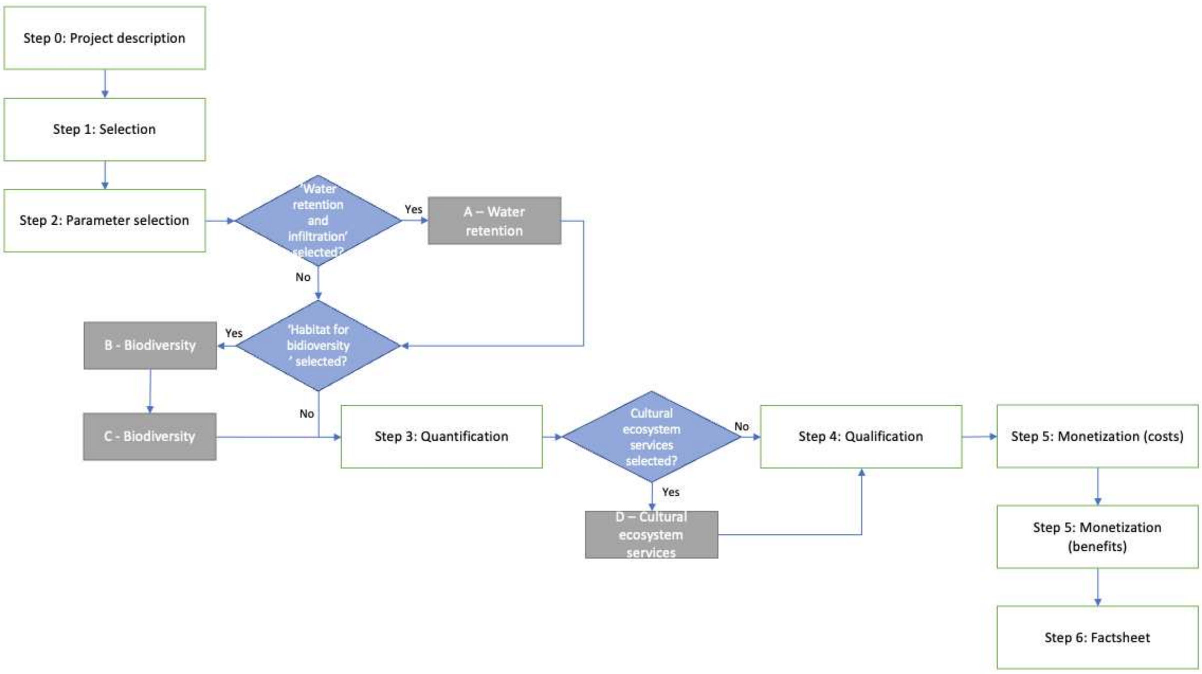


Figure 3: Step-by-step user flow in the NSC-BM Excel tool, with the sequential Excel worksheets depicted. Users always start with Step 0: Project description (top left corner) – following the arrows, conditional on ecosystem service selection (Step 1) - to end on the bottom right corner with Step 6: Factsheet.

Case study

To demonstrate the BM's functioning, and how it produces and visualizes evidence for a local authorities' greening projects' planning and design stages, we illustrate this through a case-study using a real-life GI case. A decision-makers' view was taken to describe and evaluate different spatial interpretations of the study site. The evaluation is based on the criteria that were identified as highly relevant for the pilot case by the municipality. By illustrating how the NSC-BM can be used to enhance spatial designs in terms of ecosystem generation in GI projects at early stage, we arrive at an indication of the usability and added value for local authorities.

One of the pilot cases in the Nature Smart Cities project that served to co-develop and co-design the business model is situated in the small municipality of Kapelle, the Netherlands (approx. 13,000 inhabitants in 2022). In Wemeldinge Noordzijde, a neighbourhood in the municipality of Kapelle, a regeneration project was planned, to respond to increased frequencies of extreme weather events and the structural vulnerability of the neighbourhood to floodings. The project took the form of a climate adaptive design. After several consultation and participation rounds with local residents and the design team, the municipality arrived at an ambitious greening scenario aimed at building resilience and creating a pleasant living environment for local inhabitants. The project area covers 60,000 m^2 in a residential neighbourhood, see figure 4. In this case study, methods to quantify and monetize are briefly touched upon. However, for a detailed overview of the data and methods used for ecosystem service quantification and monetization, we refer to the technical manual of the Nature Smart Cities Business Model (available from https://www.uantwerpen.be/en/centres/environment-sustainable-development/research/projects/nature-smart-cities/page3/).

Figure 4: Map of the pilot case project in Wemeldinge Noordzijde, Kapelle. The map shows how the municipality aims to improve local GI provision by making streets (semi-)permeable and by enhancing the design of existing green space.

Data gathering

The sequence of steps presented in this case study chapter is analogous to the business model flow from figure 3. In this flow, steps 0 to 2 are used as data gathering steps, results are then presented from step 3 onwards. To illustrate every step, the output from the Nature Smart Cities business model is displayed.

Step 0: Scenario description

In the first step of the NSC-BM, the user is expected to describe the spatial interpretation the baseline scenario, as well as describe how the landscape might change in the future. The number of alternative scenarios that can be submitted is unlimited, although for reasons of clarity, it is recommended to enter between 4 and 6, to not overcomplicate the assessment. Landscape categories and types are preprogramed and can be selected through drop-down menus.

For the case-study site, three scenarios were defined. The first scenario is the baseline scenario, describing the spatial elements and their representation at the beginning of the project. The second scenario is the Revitalization scenario, this is the original project plan and what was eventually realised by the municipality. This plan corresponds with the municipal strategic plans to realise a 10% increase in the quantity of GI. It involves the construction of permeable streets and parking spaces, and the building of wdis to remediate flood risks. Additionally, large (sick) trees were replaced by new trees. Since the NSC-BM could not be used in the earliest project design stages due to project timings, we have defined a third scenario (revitalization PLUS), in which the impact of spatial designs can be straightforwardly upgraded with limited budget impacts, using the intelligence that is generated by the NSC-BM. In this scenario, a small portion of the amenity grassland was replaced by alternative green elements: small trees, flower fields, shrubby plants, and tall grass.

Table 1: Description of the baseline, revitalization, and revitalization PLUS scenarios in terms of land use surfaces, output from NSC-BM

	Category	Type	Amount
Baseline scenario	Low green	Amenity grassland	11,850 m^2
	Grey infrastructure	Impermeable surface	18,150 m^2
	Grey infrastructure	Normal roof	30,000 m^2
	Trees and shrubs	Single tree (6m-12m)	46
	Trees and shrubs	Single tree (>12m)	20
Revitalization scenario	Low green	Amenity grassland	10,515 m^2
	Grey infrastructure	Impermeable surface	11,270 m^2
	(Semi-) permeable surface	Semi-permeable grow-through pavers	6,940 m^2
	Grey infrastructure	Normal roof	30,000 m^2
	Sustainable drainage systems	Trench-troughs or wadis	1,275 m^2
	Trees and shrubs	Single tree (6m-12m)	90
Revitalization PLUS scenario	Low green	Amenity grassland	9,500 m^2
	Grey infrastructure	Impermeable surface	11,270 m^2
	(Semi-)permeable surface	Semi-permeable grow-through pavers	6,940 m^2
	Grey infrastructure	Normal roof	30,000 m^2
	Sustainable drainage systems	Trench-troughs or wadis	1,275 m^2
	Trees and shrubs	Single tree (6m-12m)	90
	Trees and shrubs	Single tree (<6m)	20
	Low green	Flower field	500 m^2
	Trees and shrubs	Shrubby plants	300 m^2
	Low green	Tall grass	215 m^2

Step 1: Ecosystem service selection

According to the specific context of the municipality, or the stakeholder the users wishes to communicate with, ecosystem services for the assessment are selected. In the case study, Kapelle's climate and sustainability officer chose four ecosystem services as arguments to put in front of decision makers. The main objective of the project is building in climate resilience, specifically **alleviating flooding** risks since the area is vulnerable to rainwater floods, but **microclimate regulation** is also an important selling point in the administration. Since Kapelle is situated in Zeeland province, where one fourth of the Netherlands' fruit production takes place, the region emphasizes the importance of pollinators and new projects must therefore consider their **impact on biodiversity**. Lastly, the project area consists of a residential neighbourhood, hence the choice to include the residents' **aesthetic appreciation** of the living environment as a decision criterion.

Step 2: Parameter selection

The underlying formulas for the valuation and monetization of ecosystem services requires additional information. Values that are provided in this section support the underlying calculations in later worksheets. For some ecosystem services, no additional information is required, for others there is. Table 2 presents an overview of the information that is required for Kapelle's chosen ecosystem services.

Table 2: Overview of parameters required for calculations based on ES selection, output from NSC-BM. Data needed depends on the ecosystem services selection. The values in column three are case-specific.

Ecosystem service	Necessary data for calculations	Value
Habitat for biodiversity	No additional parameters required in this step	
Aesthetic appreciation	Number of residents living in or around (max 100m radius) the project area	911
Microclimate regulation	Number of houses in close proximity (max 100m radius) of project area	414
	Average price of electricity (€/kWh)	€0.40
	Average yearly electricity consumption per family in your region (in kWh)?	3200 kWh
Water retention and infiltration	Average precipitation per year (in m^3 per m^2 per year)	0.675 m^3
	Do you intend to collect water from outside the project area (e.g., surrounding roofs)?	No

Worksheet A - water retention

The retention coefficient (RC) denotes the percentage of runoff that will be retained by GI. By combining the average yearly rainfall, the surface area of different GI types, and the retention coefficients, the BM calculates the quantity of yearly retained runoff. This method of quantification is similar to Nature Value Explorer's (Hendrix et al., 2015) and Flemish research bundling and operationalizing research on retention coefficients (Verbeeck et al., 2014) (table 3). The quantification is automized to be employable by non-experts.

Table 3: Overview of water retention and infiltration capacity for the different surface types of the spatial scenarios, output from NSC-BM

Surface type	Baseline scenario	Revitalization scenario	Revitalization PLUS scenario	
	Area (m^2)	Area (m^2)	Area (m^2)	RC (%)
Lawn & amenity grassland	11,850	10,515	9,500	72
Trees	3,382	3,330	3,610	51
Impermeable	48,150	41,270	41,270	2
Water elements	0	1,275	1,275	100
Semi-permeable	0	6,940	6,940	70
Tall grass & flower fields	0	0	715	100
Middle green	0	0	300	78

RC: retention coefficient

Worksheets B - Biodiversity

The tool's biodiversity assessment is threefold: extent of habitat types, a land use diversity calculation, and a habitat potential for specific species estimation. The first component to quantify is the extent of habitat types. These types are lawn, tall grass, middle green, trees, semi-permeable land, vegetable gardens and water elements, and are drawn directly from the project description users made in the first step. Each measured location can only have one habitat type (even though overlap such as lawns with trees can occur) to achieve a total habitat area that is equal to the project area, apart from impermeable grey surfaces.

The second component, land use diversity, is quantified by using a diversity index. This is a quantitative measure that indicates the types of land use present in a spatial scenario and simultaneously considers richness and evenness (Tucker et al., 2017). These indices are often, though not exclusively, used in ecological research as biodiversity indices. The effective number of species (ENS) is an example of such an index. ENS is an extension to the Shannon-Weaver index (eq. 1), accounting for evenness or entropy. The ENS transforms the Shannon-Weaver index in the more intuitive measure of units of effective species (Jost, 2006). ENS denotes the number of species in an equivalent community (i.e., with the same Shannon index) where all species or land use types are equally abundant. In case of a perfectly even community, the ENS equals the number of species (S) in the project area (Zelený et al., 2021). As estimating population sizes would be too elaborate for a biodiversity estimation, the indices were used to assess land use diversity. The effective number of habitat types is calculated through equation 2. The maximal number of habitat types is equal to the number of different habitats of which the area is not 0 m².

Shannon-Weaver index (H'):

$$H' = -\sum_{i=1}^{S} p_i . \ln p_i = -\sum_{i=1}^{S} \frac{n_i}{N} . \ln \frac{n_i}{N} \qquad (1)$$

Effective number of habitat types (D):

$$D = \exp\,(\mathrm{H'}) \qquad (2)$$

with

i the species number, in this case the cover type (such as lawn or trees)

S the number of species in the researched area, in this case the number of habitat types

n_i the degree of coverage by species i, in this case the total area of habitat layer i

N = total degree of coverage, in this case the total area (or the sum of all habitat layer areas)

For this case study, the structural variation is calculated by using the information in worksheet B – Biodiversity, depicted in table 4.

Table 4: Overview of surfaces contributing to the structural variation of the different spatial scenarios, output from NSC-BM

	Baseline scenario	Revitalization scenario	Revitalization PLUS scenario
	Area (m^2)	Area (m^2)	Area (m^2)
Lawn & Amenity grassland	11,850	10,515	9,500
Overgrown	0	0	0
Tall grass	0	0	215
Flower field	0	0	500
Middle green	0	0	300
Trees	3,382	3,330	3,610
Water elements	0	1,275	1,275
Semi-permeable	0	6,940	6,940
Allotment garden	0	0	0

Worksheet C - Biodiversity

The last component of the biodiversity assessment in the NSC-BM focuses on target species. By expert judgment a list of 34 target species was selected from different taxonomic groups: birds, butterflies, bees, and amphibians (see Supplementary materials). The selection is based on different variables, such as species' characteristics, habitat requirements, occurrence in western Europe (2-seas area in particular), observations, etc. Experts at the UGent's Forest & Nature Lab (ForNaLab) contributed to the selection and the formulation of habitat requirements. In the tool, the potential of target species' presence for different scenarios is estimated. This is done by examining the target species' minimum habitat requirements based on their respective life cycles (food supply, nesting opportunity and places for overwintering or shelter) (Weisser & Hauck, 2017). By selecting "yes" or "no" in a list of various possible landscape elements a scenario is assessed on the potential of being a suitable habitat for specific target species. In table 5 the assessment was carried out for our case study in Kapelle.

Table 5: Oversight of assessment of potential habitat for biodiversity for every spatial scenario, output from NSC-BM

Landscape elements	**Baseline scenario Presence: YES/NO**	**Revitalization scenario Presence: YES/NO**	**Revitalization PLUS scenario Presence: YES/NO**
Lawn	YES	YES	YES
Tall grass	NO	NO	YES
Flower field/meadow	NO	NO	YES
Flower border	NO	NO	NO
Planter	NO	NO	NO
Herbaceous/shrubby plants	NO	NO	YES
Hedge	NO	NO	NO
Tree	YES	YES	YES
Forest	NO	NO	NO
Allotment garden	NO	NO	NO
Berry garden	NO	NO	NO
Green roof	NO	NO	NO
Compost heap	NO	NO	NO
Dead wood	NO	NO	NO

Beehive/beehotel	NO	NO	YES
Birdshouse	NO	NO	YES
Bird feed	NO	NO	NO
Overgrown	NO	NO	NO
Leaves	NO	NO	NO
Green façade	NO	NO	NO
Blue elements	NO	YES	YES
Bare land (acre/fallow land)	NO	NO	NO
Blue elements (if present):			
Conditions			
Standing water	NO	NO	NO
Population of fish present	NO	NO	NO
Elements			
Eutrophic	NO	NO	NO
Oligotrophic	NO	NO	NO
Shaded water feature	NO	NO	NO
Water element with direct light	NO	NO	NO
Water without vegetation	NO	NO	NO
Water with vertical vegetation	NO	NO	NO
Water with horizontal vegetation?	NO	NO	NO

Worksheet D – Cultural ecosystem services

Users selecting cultural ecosystem services (CES) are prompted with statements to introduce a grounded assessment method. To reduce the subjectivity of the CES assessment, every CES score is built from responses to multiple standardized statements. Each of these needs to be weighted according to its importance, on a scale of 1 to 5, and then scored for each scenario on a scale of 0 to 3. This allows a combined assessment of relative importance and effectiveness of delivery for the stakeholder. The questions are derived from academic literature and expert consultation and is designed collaboratively with colleagues from Imperial College, London (see Supplementary materials 'CES Framework'). The only cultural ecosystem service that the municipality of Kapelle prioritized in its assessment is aesthetic appreciation. The calculation for aesthetic appreciation relies on the importance weighting and scoring and is executed by the user. For the pilot case, this led to the inputs depicted in table 6.

Table 6: Overview of the assessment of cultural ecosystem service Aesthetic Appreciation, output from NSC-BM

Statement	Importance weighing	Baseline scenario	Revitalization scenario	Revitalization PLUS scenario
Does this scenario provide an aesthetically attractive place to live or work in?	3	0	2	2
Does this scenario provide an aesthetically attractive place to live or work in?	1	0	0	0
Does this scenario make outdoor activities more enjoyable?	1	0	0	0

Does this scenario include an attractive mix of different landscape elements?	2	1	1	1
Does this scenario promote people's engagement with the natural world?	2	0	1	2
Does this scenario create, or add to, a sense of place and visual identity?	4	0	3	3
Do people enjoy spending time in and around this scenario area?	1	0	0	0
Does this scenario contribute towards civic pride in the locality?	1	0	0	0

Results

The results of the pilot case study are summarized on three different levels, referring to figure 2, the valuation pyramid. From demonstrator testing, we found that local officers felt uncomfortable with the subjectivity of the qualitative assessment part of the business model flow. Hence, it was decided to provide users first with quantified evidence of ecosystem services impacts (if the ES was quantifiable), and with the assessment for cultural ecosystem services. After this, further testing indicated that much of the uncertainty that originated the concerns of subjectivity was resolved.

For the Wemeldinge Noordzijde case, three out of four selected ecosystem services were quantified: (outdoor) Microclimate regulation, water retention and infiltration, and habitat for biodiversity. The results are shown in figure 5.

Step 3: Quantification

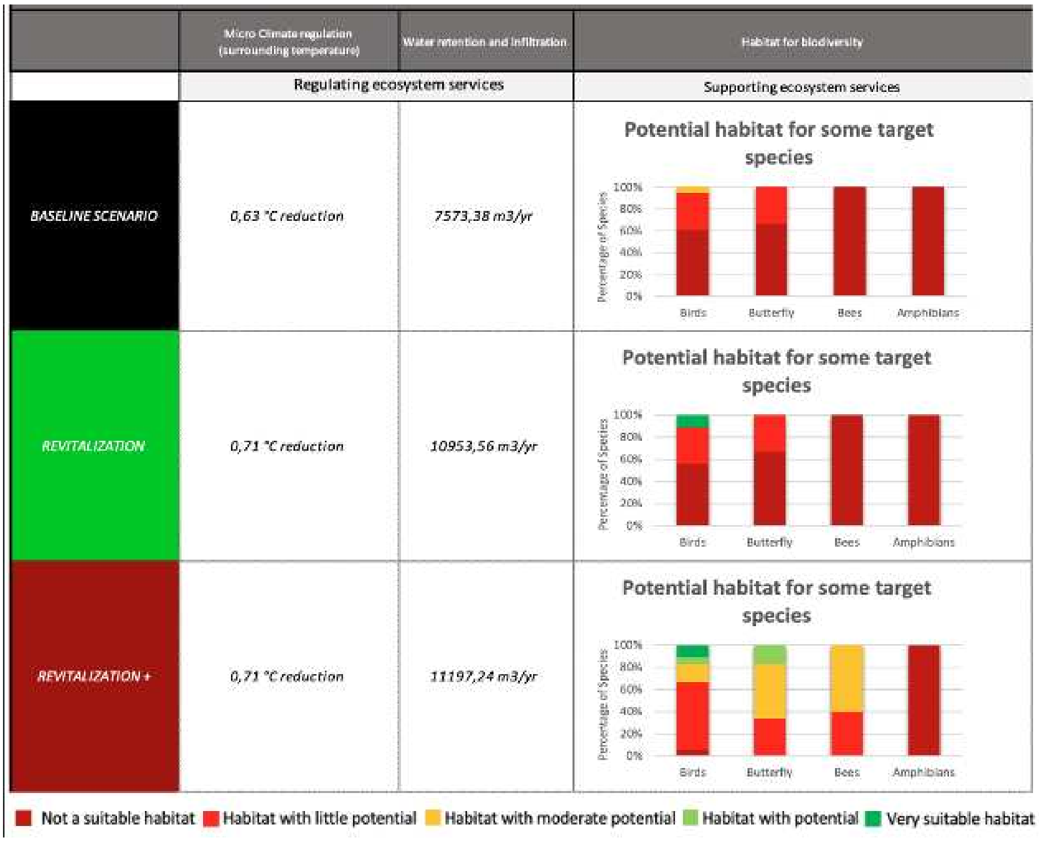


Figure 5: Oversight of the quantitative results for different spatial scenarios, output from NSC-BM

Noticeably, microclimate regulation only slightly improves because of the green infrastructure that was already present in the baseline scenario. The method to quantify is a simplified application of Ziter et al. (2019). Instead of circles to estimate air temperature differences, the average effect on the project's local air temperature was estimated as a weighted average (assuming equal distribution over project area) of GI types and their cooling capacity and their relative surfaces. These values are benchmarked to an all-grey spatial scenario; hence the baseline scenario has a local air temperature reducing effect as well.

The water retention and infiltration capacity of the area improved considerably. The replacement of impermeable pavements by all semi-permeable pavements that enhances the retention capacity by over 40% compared to the baseline scenario.

The result for biodiversity depicts the suitability (in %) of the habitat for every target species. These percentages of the target species are harmonized within the taxonomic group as an overview of the impact of certain measures (De Beelde & Mertens, 2021). In the case study example, it is found that there is progress on the habitat suitability for a few of the bird species, advancing from 'a habitat with moderate potential' to a 'very suitable habitat'. Besides this, no other species are expected to benefit from the current plans for revitalization. The small adjustments from revitalization to revitalization PLUS however, reveal considerable improvements in the habitat for biodiversity. Birds, butterflies, and bees are all expected to have more habitat potential in this scenario. The Shannon-Weaver index and ENS index regarding structural variation support this result. The ENS increases from 1.70 in the baseline scenario to 3.21 in revitalization and 3.94 in the revitalization PLUS. Interpreting this, we notice the ENS is expected to double by the 10% increase in local green space surface area, and a further 22% increase solely by more GI variation. This underlines the notion that green space quality is often more important than quantity but demonstrates this transparently and makes it tangible for users.

Step 4: Qualification

Users are expected to score the performance of every scenario on the different ES on a scale from 0 (no contribution to ES level/outcome) to 3 (excellent contribution to desired ES level/outcome). This exercise is facilitated by displaying quantitative results first for the quantitatively assessable ES, for the CES the scoring is automatically loaded from worksheet D – Cultural ecosystem services. The qualified results are visualized in a spider diagram (Figure 6).

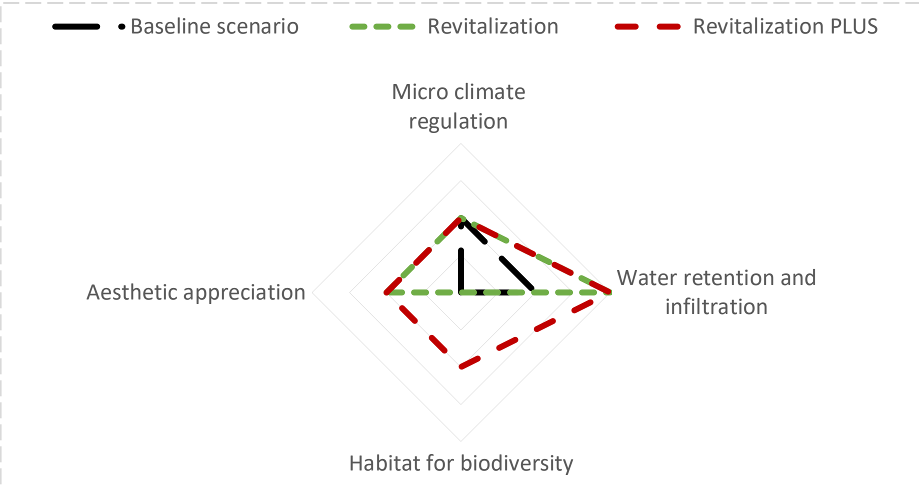


Figure 6: Qualitative scenario comparison produced through the NSC-BM, the number of axis are self-adjusted and based on the number of ecosystem services chosen.

Step 5: Monetization (costs)

Where possible, the data library is composed of minimum and maximum values for construction and maintenance costs, drawn from (grey) literature research. The cost data library provides indications of costs per unit of different infrastructure types. Hence, scenario costs are calculated by multiplying these unit costs with the number of units present in each scenario. Users are strongly recommended to utilize local values at their LA's disposition to overwrite data library information in the custom values columns) as this improves the accuracy of the outcomes. Moreover, several costs depend heavily on the materials used, the environment of intervention, and local circumstances. Therefore, these monetary cost estimations (see table 8) should be interpreted as indicative, and allowing comparisons with other scenarios, rather than accurate point estimates. Before starting the calculations, users are given the option to change currencies, discount rates, and to opt for a minimum, average, or maximum cost calculation. In the case study, the municipality of Kapelle opted for the average cost calculation and a (default) discount rate of 3.5%.

In total, the construction cost for the revitalization is estimated at €587,888, for the plus scenario €592,108. Since it already exists, the baseline has no construction costs. Comparing the anticipated maintenance cost, we find that the baseline scenario has a yearly estimated maintenance cost of €109,773.37, the revitalization lands at €110,772.85, and for the plus scenario €112,816 is found. However, a large portion (€99,000) of these maintenance costs originate from maintenance to normal roofs (equal in every scenario), which are privately owned and thus should not weigh on the municipal decision.

Table 7: Costs for every scenario as estimated by the NSC-BM

		Construction cost (range)	Custom value	Maintenance cost/year (range)	Quantity newly built	Total construction cost	Total maintenance cost (annually)
Baseline scenario	Amenity grassland	[11,20]	/	[0.39; 0.39]	0	/	€ 4,621.50
	Impermeable surface	[100, 112]	/	[0.23; 0.27]	0	/	€ 4,590.64
	Normal roof	[30, 80]	/	[3; 3.6]	0	/	€ 99,000
	Single tree (6m-12m)	[54.88; 70]	/	[10; 37.31]	0	/	€ 1,088.13
	Single tree (>12m)	/	/	[10; 37.31]	0	/	€ 473.10
TOTAL						/	€ 109,773.37
Revitalization scenario	Amenity grassland	[11,20]	16	[0.39; 0.39]	4468 m^2	€ 71,488	€ 4,100.85
	Impermeable surface	[100, 112]	20	[0.23; 0.27]	11270 m^2	€ 225,400	€ 2,850.50
	Semi-permeable grow-through pavers	[21, 30]	37.5	[0.21; 0.43]	6940 m^2	€ 260,250	€ 2,220.80
	Normal roof	[30, 80]		[3; 3.6]	0	0	€ 99,000
	Trench-troughs or wadis	[6.10; 6.10]	10	[0.37; 0.37]	1275 m^2	€ 12,750	€ 471.75
	Single tree (6m-12m)	[54.88; 70]	200	[10; 37.31]	90 trees	€ 18,000	€ 2,128.95
TOTAL						€ 587,888	€ 110,777.35
Revitalization PLUS scenario	Amenity grassland	[11,20]	16	[0.39; 0.39]	3453 m^2	€ 55,248	€ 3,705
	Impermeable surface	[100, 112]	20	[0.23; 0.27]	11270 m^2	€ 225,400	€ 2,850.50
	Semi-permeable grow-through pavers	[21, 30]	37.5	[0.21; 0.43]	6940 m^2	€ 260,250	€ 2,220.80
	Normal roof	[30, 80]		[3; 3.6]	0	0	€ 99,000
	Trench-troughs or wadis	[6.10; 6.10]	10	[0.37; 0.37]	1275 m^2	€ 12,750	€ 471.75
	Single tree (6m-12m)	[54.88; 70]	200	[10; 37.31]	90 trees	€ 18,000	€ 2,128.95
	Single tree (<6m)	[54.88; 70]	200	[10; 37.31]	20 trees	€ 160	€ 463.10
	Tall grass	[10; 30]		[0.33; 0.33]	215 m^2	€ 4,300	€ 70.95
	Flower field	[10; 30]		[0.31; 0.31]	500 m^2	€ 10,000	€ 155
	Shrubby plants	[10; 30]		[5.80; 5.80]	300 m^2	€ 6000	€ 1740
TOTAL						€ 592,108	€ 112,816

Step 5: Monetization benefits

Three out of the four selected ecosystem services are monetizable (see table 9). For microclimate regulation, this monetized benefit is the sum of avoided cooling costs and the effects of improved thermal comfort (Alves et al., 2019; CRC for Water Sensitive Cities 2016). Based on the cooling effect that was calculated in step 3: quantification (figure 5) and the values inserted in step 2: parameter selection (table 2), yearly and total economic values are derived. For water retention and infiltration, the method to monetize was replicated from Nature Value Explorer (Hendrix et al., 2015). The monetization originates from the avoided cost of sewage treatment and the portion of taxpayers' contribution to water drainage that can be attributed to rainwater drainage. For aesthetic appreciation, monetization is based on Wang et al. (2014), who conducted a review bundling ecosystem service valuation studies. A more detailed overview of the methods used can be accessed through the Nature Smart Cities technical manual, pages 12-55. All benefit streams are discounted at a discount rate of 3.5%.

Table 8: Estimated monetized benefits for every spatial

		Annual benefit	Total benefit (20 years)	Total benefit (40 years)
Baseline scenario	Microclimate regulation	€ 15,297.09	€ 222,727.73	€ 331,952.37
	Water retention and infiltration	€ 4,959.16	€ 72,206.02	€ 107,615.53
	Habitat for Biodiversity	/	/	/
	Aesthetic appreciation	€ 759.17	€ 11,053.55	€ 16,474.14
TOTAL		€ 21,015.42	€ 305,987.3	€ 456,042.04
Revitalization	Microclimate regulation	€ 17,239.58	€ 251,010.63	€ 374,105.02
	Water retention and infiltration	€ 7,172.56	€ 104,433.37	€ 155,647.00
	Habitat for Biodiversity	/	/	/
	Aesthetic appreciation	€ 5,314.17	€ 77,374.99	€ 115,319.31
TOTAL		€ 29,726.31	€ 432,818.99	€ 645,071.33
Revitalization PLUS	Microclimate regulation	€ 17,239.58	€ 251,010.63	€ 374,105.02
	Water retention and infiltration	€ 7,332.12	€ 106,756.62	€ 159,109.56
	Habitat for Biodiversity	/	/	/
	Aesthetic appreciation	€ 6,073.33	€ 88,428.55	€ 131,793.48
TOTAL		€ 30,645.03	€ 446,195.40	€ 665,008.06

Discussion

In this paper we present a novel tool to examine the ecosystem services or co-benefits that are generated through green infrastructure or nature-based solutions, specifically applicable in urbanized contexts and at early project stages. Through intense co-creation and co-design between academic and city partners in the Interreg 2seas Nature Smart Cities project, this tool fills a gap in current municipal spatial planning and design practices, by integrating ecosystem services thinking. Both internal and external testing and validation phases have confirmed the potential of the tool. Through applying the framework in a real-life case study, we demonstrate what the Nature Smart Cities Business Model can and cannot do.

The application of the case study clearly establishes the main objective of the BM. The BM was developed to provide the means for local authorities to straightforwardly compare several different spatial scenarios in terms of the impacts on ecosystem services and values that they produce. By offering a framework that is adaptable to the specific decision-making context, users can prioritize those ecosystem services that are valued most strongly by the stakeholders they wish to communicate with. In that sense, the BM offers the added value to adapt the key message in terms of the selection of co-benefits to the target audience, making it a strategically valuable instrument for local use.

In the case study, since the project area is vulnerable for torrential floodings, 'water retention and infiltration' is highly prioritized. Through using the tool, the municipality is not only able to quickly generate an indication of the retention capacity of the project area but is also explicitly provided with ideas for landscape elements that would improve the water retention capacity locally. As the assessment indicates, the revitalization project leads to an estimated improvement in water retention and infiltration capacity of over 44% within the project boundaries. This leads to avoided sewage treatment costs, mounting up to over €7,000 of expenses avoided yearly.

As regards microclimate regulation, it is noticeable that there is a very limited effect between the initial baseline state and the revitalization of the neighbourhood. Comparing the scenarios, a modest mean temperature decrease of 0.07°C is expected between the baseline and either of the revitalization scenarios.

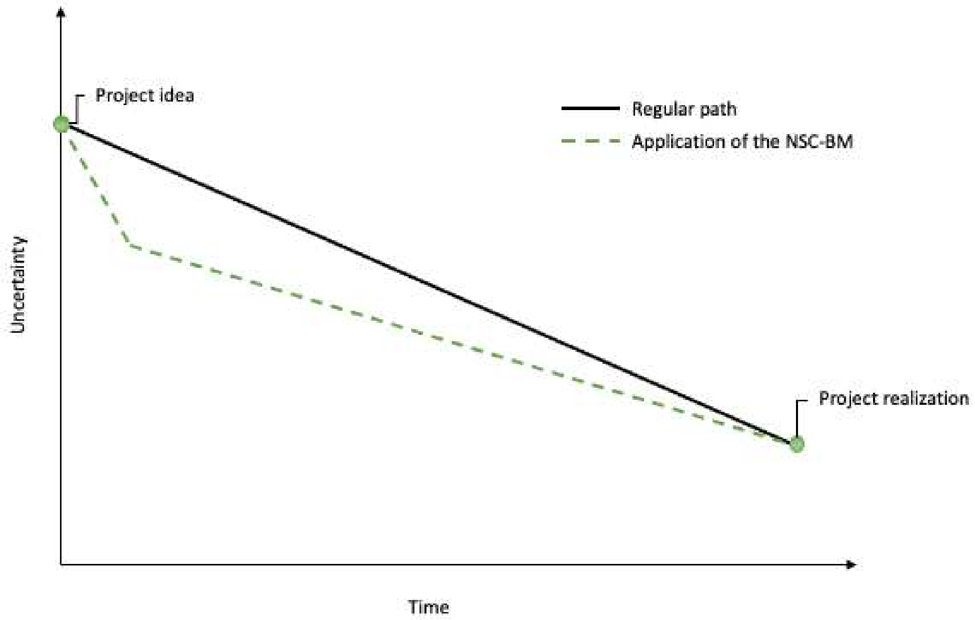
On top of trade-offs that occur across ecosystem service values, the structure of the NSC-BM allows exploring trade-offs in the estimated cost-benefit structure of a project's lifetime. In the case study, we find that maintenance costs are expected to be slightly higher in the revitalization project. On the other hand, there is considerable added value created through the revitalization. The estimated monetary benefits of *aesthetic appreciation* and *water retention and infiltration* indicate that the annual added benefits (from €21,015 to €29,726) amply outweigh the additional yearly maintenance costs (from €109,773 to €110,777). Given that these maintenance costs are dominated by yearly maintenance to private house owners' normal roofs (€99,000), we can even conclude that the (small selection) of benefits outweigh the costs. All these results are summarized in a factsheet. We stress that the absolute values of these calculations are less informative than their comparisons relative to other spatial scenarios.

One of the main innovations of the NSC-BM is the fact that it facilitates the use of MCDA in very early project stages by developing an automated framework, which allows users to generate quick estimations on the outcome of different land-use scenarios. With the revitalization PLUS scenario in the case study, we illustrate the relevance of early-stage application of the tool. If the NSC-BM had been applied in the initial stages of our pilot case, the shortcomings on biodiversity would have been identified, prompting remedial action to improve the project design. With the results of the revitalization PLUS scenario, we find that for an increase in project costs with less than 1%, not only could biodiversity have been improved considerably, but other co-benefits could also have been enhanced. This illustrates that the advancement of the NSC-BM does not lie in methodological or modelling improvements to the state-of-the-art, bur instead consolidates information and data from various sources transparently, facilitating the application of scientifically reviewed data in day-to-day spatial planning and decision making. We illustrate how this could lead to significant improvements in GI design, with little effort.

Since the tool builds further on existing ES valuation tools and practices, it does not try to reinvent the wheel. The fact that the tool is designed for application at finer-scale levels is innovative in itself (Hansen et al., 2019). Moreover, emphasis of the project was put on involving key stakeholders in urban planning and design projects. By creating and designing a tool not only **for** target users, but especially **with** target users (Voskamp et al., 2021), the Nature Smart Cities business model fulfils users' needs and expectations more accurately than previous attempts. Furthermore, co-creation and co-development encourages engagement from local decision-makers, which helps translating visions into actions (Guerry et al., 2015). With the NSC-BM, the developers have created a pragmatically designed framework that overcomes existing GI implementation gaps.

The focus on early project stages results from literature review with existing tools (Van Oijstaeijen et al., 2020). If a tool has the specific aim for usability by local officers, this implies reductionist approaches. Hence, these tools should be deployed in early project stages to lower initial uncertainties, where the results might provide information for later-stage in-depth ecosystem services assessments. Figure 7 illustrates how small-scale spatial GI planning projects' uncertainty evolves over time. The objective of the NSC-BM is to translate some of the initial complexities of ES generation to the operational level, thereby reducing uncertainty considerably when progressing from a project idea. Ultimately, this aims to enhance the probability of approval of GI investments by providing stronger arguments in discussions on spatial planning characterized by conflicting interests.

Figure 7: Positioning of the NSC-BM in project development



The NSC-BM further adds to current practice by establishing a framework for low-level impact assessment of future developments on cultural ecosystem services, and on biodiversity. The introduction of a series of literature-based directive questions to estimate how GI projects influence the generation of cultural ES is an important addition to existing tools. Users can adapt the assessment (to a limited extent) to their decision-making context, by indicating which aspects are most highly valued by the stakeholders in question. Explicitly revealing these cultural benefits may contribute to their current undervaluation – with the exception of recreation (Cortinovis & Geneletti, 2018) - in local spatial planning spheres. Regarding habitat for biodiversity, an easily interpretable method of impact estimation on the habitat potential of a selection of target species within four taxonomic groups (bees, butterflies, birds and amphibians) is provided. This method is accompanied by a calculation of the Shannon-Weaver index and ENS index, based on the acknowledgement that structural diversity contributes to biodiversity. The NSC-BM is the first tool that offers an estimation for habitat for biodiversity within a broader framework of project-scale GI or ES co-benefits assessment. Thus it introduces the dimension of restorative and regenerative actions that enable non-human species to thrive (Bayulken et al., 2021), providing local officers with tangible and interpretable evidence of the importance of green space quality, beyond mere quantity. The demonstrator testing showed that this part moved local officers to tweak their designs, adding landscape elements that would improve the biodiversity potential of a project site.

Popularizing access to ES information without excessive time or resource demands assists local officers in building stronger cases for GI investments in early project stages. The practical utilization of the ES concept is thought of as broadening the scope of the planning process (Longato et al., 2021). This was confirmed in the stage of demonstrator testing, where officers stated that applying the tool to their case inspired them to go back to the drawing board and improve the delivery of ES that weren't fully considered yet (Back, 2021). Moreover, by providing this information in an easily interpretable and visual way, the tool acknowledges the need for benefits to be assessed in terms that practitioners and decision-makers understand (Bayulken et al., 2021). Users can opt to include those criteria (or ecosystem services) that are deemed relevant within the context of the assessment. As well as being a design and planning support tool, it might therefore also serve as a means of (strategic) communication. The usability and credibility of the tool was further supported by a step-by-step guidance document (available in English, French, and Dutch) and a technical manual with all the methods and data sources referenced. Both documents can be found in supplementary materials.

A common barrier to GI/NBS implementation at municipal level is silo-based thinking (Wihlborg et al., 2019); integrated assessments can address such barriers. The NSC-BM's ecological, social, and economic valuation methods cross traditional departmental boundaries, which might foster cooperation and integration at local authority level. Apart from the benefit-side, the NSC-BM goes beyond the current state-of-the-art by providing estimations on the cost-side, something no other GI decision-support tool is doing (Van Oijstaeijen et al., 2020). This comprehensiveness was an explicit aspiration from local authorities.

Currently, the NSC-BM and its data library are limited to be employed by Las in Western-European countries, more specifically the Interreg 2seas-region. Especially for the biodiversity assessment, extensions to the current framework would be needed for other regions. Currently, a tool has been developed that can be widely used, but making the tool more spatially explicit, accommodating local geographical and climatic variables for example (Juhola, 2018), should be envisioned with next versions of the NSC-BM. This would require developing the tool into an online and web-based tool. As this benefits the user interface and is computationally more stable, it provides a clear pathway for future research. Regarding ES valuation, methods to refine current estimation methods without increasing complexity for the user should be considered, always in collaboration with local authorities. Another limitation of the current version is its dependence on 'quick and dirty' benefit transfer methods. Addressing the issue of spatial explicitness in the future will therefore be useful to improve the benefit transfer functions. Acknowledging GI social needs and social justice, combined with ecological justice (Pineda-Pinto et al., 2022) is another opportunity for geographically specific tools.

Monetization (of ecosystem services) is a subject of debate, especially when considering transferability and universality. While the ES values that are market-based estimates (e.g., food production, carbon sequestration) are easily transferable, other value calculation methods used in the tool (e.g., avoided costs, and results from stated preference methods) are heavily influenced by the socio-cultural and economic context of the area in question. Application outside of the target area is therefore discouraged in the current version of the tool. Monetization in terms of costs is equally sensitive to local differences. Even within the target region, regional and contextual variability might be significant. The developers advise to overwrite the data library with local information where possible, to increase accuracy of the results. Further, it is important to underline that the NSC-BM is intended for early-project stages. It is not the aspiration of the tool to provide exact values, but rather indications of the order of magnitude, and a scenario comparison to assist local officers in choosing a way forward and in building a GI case.

A further limitation of this research is the narrow interpretation of a *business model* within this framework of a comprehensive value assessment, leaving a few optimization gaps for future research. Two specific dimensions complementary to the current framework, which have not been addressed in other tools either, are worth mentioning in that respect: (innovative) financing of GI and value capturing perspectives. Facilitating access to different financing options for local authorities would contribute further to translation from strategic vision into concrete actions but are out of scope for this current tool. However, by continuing to monitor the user experience in the future, the developers aim to respond to changing decision-making contexts.

Conclusion

In this paper, the authors introduce a novel tool resulting from the Interreg 2seas Nature Smart Cities project. The NSC project aimed to facilitate green infrastructure implementation at the local scale to improve the climate resilience of local municipalities. The automated Excel tool that was developed provides local officers with objective arguments for green infrastructure investments without requiring expert consultation. By popularising the access to ecosystem services information in initial project stages users benefit in improving the case for green infrastructure projects, removing a part of the uncertainty that previous research identified as one of the bottlenecks in effective GI investments.

The main contribution of the NSC-BM over existing tools lies in its applicability by local officers. Since the NSC-BM is the product of intensive co-creation and co-design between academia and practitioners, the tool is tailored to the specific needs and requirements that are expressed by members of the target audience. Given the trade-off between complexity and usability that is implied in the application of tools at the local scale, the unique collaboration within the Nature Smart Cities project has provided very significant added value. Moreover, strong emphasis was put on testing the usability in practice. The demonstrator testing and capacity building phases of the project have greatly contributed to successfully addressing this. The NSC-BM offers users the basis for a multi-criteria decision analysis, supported by ecosystem services valuation. These ecosystem services are valued qualitatively, quantitatively, and (where possible) monetarily, to offer a comprehensive oversight of the impacts of spatial GI interventions. Further, the tool offers straightforward methods to assess and interpret the influence of GI interventions on cultural ecosystem services and includes a module to estimate the impact on the habitat for biodiversity. In these features, the NSC-BM goes beyond the current state-of-the-art. Lastly, the developers have included a cost estimation as well, which is unprecedented.

Through a case study in a residential area in Kapelle, The Netherlands, we demonstrate the use of the NSC-BM. The revitalization scenario as it was executed led to an estimated increase of 40% in water retention and infiltrating capacity locally. The assessment indicates a small increase in the cooling capacity of the area as the result of the increased share of green infrastructure, averaging at 0.71°C compared to an all-grey situation. Further, noticeable advances are made regarding the day-to-day aesthetic appreciation of residents. In the revitalization PLUS scenario, we establish how the NSC-BM contributes to early-stage planning and design practices. By making minor adjustments to the revitalization scenario (less than 1% budget increase), the area would score significantly better on the habitat for biodiversity capacity of the area, while simultaneously making small improvements for other ecosystem services. This assessment tangibly indicates how green infrastructure quality is often more valuable than quantity and does not necessarily imply higher costs.

By applying the NSC-BM to a GI case local authorities get a very intuitive oversight of the estimated ecosystem services generation of future projects. This tool goes beyond being a mere planning tool by offering ideas to adapt and optimize designs as well. The tool was validated through a series of demonstrator tests in eight municipalities and through two series of capacity building workshops, reaching a total of 266 individuals across 133 local authorities across the 2 seas region.

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Supplementary materials

Target Species of biodiversity assessment;

Birds			Butterflies	Bees	Amphibians
Greenfinch (*chloris chloris*)	Jay (*Garrulus glandarius)*	Dunnock/Finch (*Prunella modularis)*	Peacock (*Aglais io)*	Tawny mining bee (*Andrena fulva)*	Common toad (*Bufo bufo*)
Wood pigeon (*Columba palumbus)*	Great tit (*Parus major)*	Collared dove (*Streptopelia decaocto)*	Brown sandpiper (*Maniola jurtina)*	Orange-tailed mining bee (*Andrena haemorrhoa)*	Alpine newt (*Ichthyosaura alpestris)*
Great spotted woodpecker (*Dendrocopos major)*	House sparrow (*Passer domesticus)*	Blackcap (*Sylvia atricapilla)*	Large skipper (*Ochlodes sylvanus)*	New garden bumblebee/tree bumblebee (*Bombus hortorum)*	Smooth newt (*Lissotriton vulgaris)*
Robin (*Erithacus rubecula)*	Chiffchaff (*Phylloscopus collybita)*	Wren (*Troglodytes troglodytes)*	Speckled wood (*Pararge aegeria)*	Ivy bee (*Colletes hederae)*	Green frog (*Pelophylax kl. esculentus)*
Common coot (*Fulica atra)*	Magpie (*Pica pica)*	Blackbird (*Turdus merula)*	Great cabbage white/small cabbage white (*Pieris rapae)*	European orchard bee (*Osmia cornuta)*	Common frog (*Rana temporaria)*
Moorhen (*Gallinula chloropus)*	Green woodpecker (*Picus viridis)*	Song thrush (*Turdus philomelos)*	Large skipper (*Polygonia c-album)*		