Evaluating the Multi-dimensional Impacts of the 10% Biodiversity Net Gain Requirement: A Methodological Proposal for Public Administrations

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Abstract. Biodiversity Net Gain (BNG) has been introduced in England as a mandatory planning requirement to reverse biodiversity loss and mobilize private investment in nature recovery. From February 2024, most new developments are required to deliver a measurable improvement of at least 10% in biodiversity value. With the start of BNG implementation, positive and negative externalities are emerging and since it is still in its early implementation phase, no widely validated academic framework currently exists that comprehensively evaluates its multi-dimensional impacts. In this context, we propose using the COSIMA (Composite SIgnificance and Multicriteria Assessment) framework as a tool for a holistic ex-ante evaluation of BNG projects. COSIMA integrates traditional cost-benefit analysis (CBA) with multicriteria decision analysis (MCDA) to generate a composite index called the Total Rate of Return (TRR). In this context, this framework ensures that the priorities of developers, government agencies, and local communities are reflected in the final evaluation by including a variety of criteria, both monetizable and non-monetizable. The framework was developed through a structured three-phase methodology combining an exploratory and a systematic scoping review, a stakeholder analysis, and a structured expert validation procedure involving multi-domain specialists to finalize a set of impact indicators spanning environmental, economic, social, and governance dimensions. COSIMA enables transparent, evidence-based comparison of alternative scenarios and provides public administrators and policymakers with a flexible tool to support stakeholder dialogue and optimize the BNG policy.

Keywords: Environment Act · Mitigation hierarchy · Impact assessment

1 Introduction

Biodiversity is the foundation of ecosystem functioning and provides critical ecosystem services, from food security and water purification to climate regulation and human well-being [1]. It holds both intrinsic ecological value and irreplaceable socioeconomic

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importance for human societies [2]. Despite this, biodiversity is declining at accelerating rates globally, driven by economic growth and development [3]. This trend makes it increasingly important to assess the likely ecological, economic, and social effects of biodiversity-related interventions at an early stage.

England is currently among the most nature-depleted countries in the world, having lost more than half of its native biodiversity due to centuries of urban development, habitat destruction, and intensive agriculture [4]. To reverse this trend, the UK government introduced Biodiversity Net Gain (BNG) as a mandatory requirement under the Environment Act 2021. This policy requires that most new construction projects must leave the local environment in a demonstrably better state than before construction. Specifically, the Statutory Biodiversity Metric (SBM) is used to ensure a minimum 10% gain [5, 6], a rule that has applied to most English construction projects since February 2024. This move marks a significant transition from the previous "No Net Loss" (NNL) approach, which focused on pure offsetting, towards a more proactive framework for ecological improvement [7].

BNG is in its early implementation phase and its implications at this stage are insufficiently studied, with several operational challenges already beginning to emerge. However, as a policy that only came into force in 2024, there is currently no widely validated academic framework currently integrates ecological, economic, social, and governance dimensions into a unified and stakeholder-driven assessment of the multidimensional impacts of BNG [8, 9–12].

To develop such a framework, it is necessary to examine the methodologies traditionally used for comparable initiatives. The evaluation of similar concepts to BNG such as broader environmental policies and nature-based interventions has employed a range of assessment tools. Among these, cost-benefit analysis (CBA) and multicriteria decision analysis (MCDA) have emerged as the most widely applied. CBA is formally prescribed by the UK Government's Green Book [13] and by European Commission as the main appraisal methodology for public policies [14], based on the monetization of direct costs and benefits. However, it systematically underestimates non-market ecological, social, and cultural values [15] which are critical to BNG's objectives. On the other hand, MCDA captures qualitative and multidimensional trade-offs between different stakeholder values, but lacks the economic interpretability required for public financial evaluation [16].

To address this gap, this paper proposes COSIMA (COmposite SIgnificance and Multicriteria Assessment), as an integrated decision-support framework for the ex-ante evaluation of BNG interventions. COSIMA was originally developed by Barfod and Salling for transport appraisal [17] and was later adapted for ecosystem services assessment by Oppio et al. [16]. In this study, COSIMA is extended for the BNG context by integrating into a unified Total Rate of Return (TRR) indicator [16]. The proposed framework is structured around three core stakeholder perspectives of developers, local government bodies, and local communities and based on a rigorous dual-stream review and validated by an expert panel. The scope of this paper is limited to the conceptual and methodological development of the COSIMA-based assessment framework. Its empirical application to the Italian planning context will be addressed in a subsequent research phase.

Following the definition of our research objectives, Sect. 2 reviews the current BNG policy landscape and highlights where existing assessment tools fall short. Section 3 details our methodology. Section 4 presents the final, validated list of these indicators. Section 5 discusses preliminary findings and practical policy implications. Finally, Sect. 6 summarizes the main contributions, acknowledging their limitations and suggesting future perspectives.

2 Literature Review and Policy Context

2.1 Evolution of Biodiversity Compensation

The BNG introduced by the Environment Act 2021 [5] requires new construction projects in England to increase local biodiversity by at least 10% [18]. This requirement is based on a measurable net improvement in biodiversity value, rather than on simple compensation for ecological loss. This legislation marks an evolution from the previous concept of NNL [19]. While NNL aimed simply to offset damage to maintain the status quo, BNG transforms development into an active tool for environmental restoration (Fig. 1).

The implementation of BNG is based on two key pillars. The first requires developers to give absolute priority to avoiding ecological damage, intervening with improvements only where the impact is unavoidable. The second is based on the SBM, developed by DEFRA and Natural England [20, 21]. This tool assesses the health of the environment before construction begins. By analyzing the size, quality, and characteristics of habitats, SBM provides a transparent and measurable method to ensure that the claimed benefits are real and monitorable over time. In short, BNG shifts the focus from simply limiting damage to creating long-term benefits, making the construction sector directly responsible for ecosystem regeneration.

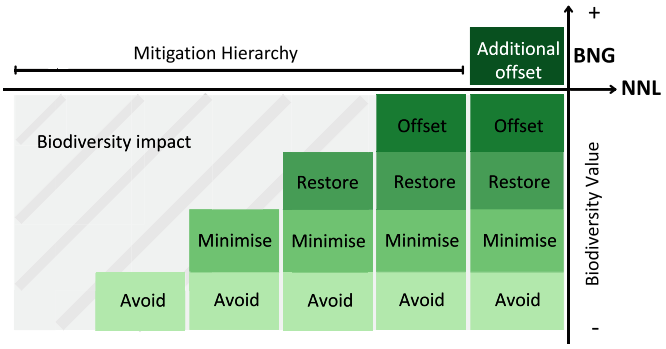

Fig. 1. Previous No Net Loss policy and the new BNG approach to mitigate biodiversity loss during development. Redrawn by the authors based on [18]

2.2 Evaluation Standards and Assessment Framework

A range of methodological frameworks have been applied in the scholarly and policy literature to assess environmental policies and nature-based interventions, including Environmental Impact Assessment (EIA), Cost-Effectiveness Analysis (CEA), MCDA, and CBA. Among these, CBA and MCDA have emerged as the most widely applied tools for capturing impacts. CBA is formally prescribed by the UK Government's Green Book as the core appraisal methodology for public policies [13]. MCDA is recommended for complex interventions involving multiple objectives and diverse groups of stakeholders. Together, these two approaches provide the methodological basis for assessing both monetizable and non-monetizable impacts, which is particularly relevant in the case of BNG. A review of grey literature has shown that the specific actions used to deliver biodiversity gain include the creation of new habitats through Nature-Based Solutions (NBS), interventions that use natural processes to deliver environmental and social benefits, and Green Infrastructure (GI), as well as the enhancement of existing habitats [6, 10]. Evidence from these similar concepts, including Ecosystem Services (ES), NBS, and GI, which share BNG's core characteristics confirms that neither CBA nor MCDA alone is sufficient. Monetary methods fail to capture social and ecological values, while qualitative approaches lack the economic rigor required for public appraisal. CBA excels at monetizing direct costs and benefits and enables transparent financial accountability. However, it systematically under-represents non-market values, including social well-being, ecological quality, and institutional trust [13, 22], that are central to BNG's objectives. MCDA captures qualitative, multi-dimensional trade-offs and incorporates diverse stakeholder values. However, it lacks the economic rigor required for public financial appraisal and can be sensitive to subjectivity in weight elicitation [16].

Stated preference methods, such as contingent valuation and choice experiments, offer a partial bridge by translating selected non-market values into monetary estimates. However, their reliance on hypothetical scenarios introduces uncertainty and limits their applicability in complex, multi-stakeholder contexts such as BNG [23].

Beyond project-level appraisal tools, several internationally recognised frameworks have also been developed to account for the values of biodiversity and ecosystem services at broader scales. The System of Environmental-Economic Accounting (SEEA EA) constitutes a statistical framework for tracking ecosystem changes at national scale [24], and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) produces scientific assessments of biodiversity at the supranational to global scales to inform international policy [2]. However, these frameworks share a common limitation in the context of BNG project appraisal. They primarily operate as accounting or assessment frameworks and are less suited to project-level ex ante option appraisal [25]. Crucially, none of these frameworks produces a single composite indicator capable of capturing how each stakeholder group experiences the impacts of a BNG project differently. Moreover, they do not provide a decision-making structure for comparing how alternative project options may affect different stakeholder groups before implementation.

2.3 Current Implementation Challenges

The implementation of the BNG program is facing significant challenges that could jeopardize the achievement of its objectives. On the one hand, the market for biodiversity units has had a slow start. By July 2024, only a few sites, totaling less than 300 ha, had been included in the Register of Biodiversity Enhancement Sites. This falls substantially short of the government's target of 6,700 ha per year [10]. On the other hand, developers are struggling to comply with the BNG. In the first five months of the policy's implementation, only 0.5% of planning applications included provisions related to the BNG. The main problem appears to be that the new rules are simply too complex to manage. The amount of paperwork and the financial burden of managing the sites for decades pose huge obstacles for developers. It is not just private developers who are struggling. The public sector is also having a difficult time. Local planning authorities are legally required to oversee BNG, but most local councils lack the resources to monitor sites and ensure compliance [12, 26].

The challenges are not only administrative and management-related. At a societal level, although local communities may benefit from improved green spaces and improved ecological quality, they may be excluded from decision-making processes regarding the location and methods of habitat creation outside the sites. This can result in biodiversity gains being concentrated in some areas, while losses occur in others, leading to an unequal distribution of benefits among different population groups [27]. These multidimensional challenges suggest that BNG may generate complex and often uneven impacts on different stakeholder groups, particularly between developers and local communities, impacts that cannot be captured through a single assessment approach.

3 Methodology

3.1 Research Design

The research adopts an integrated methodological design organized into three main phases. The approach begins with a stakeholder analysis (SA), which provides the conceptual foundation for the framework. This phase is crucial in the context of NBSs, which, as in all complex decision-making problems, involves a diverse set of actors with potentially conflicting interests. Specifically, SA allows for the identification of actors and helps clarify their roles and the ways in which they are influenced by policy.

In parallel, a review is conducted that combines grey and policy literature, with a systematic analysis of academic and scientific sources. The grey literature review contributed to understanding the actions used in implementing NBSs and their impacts, the real emerging challenges, externalities, and the starting point for future research and analysis. We also examined the academic literature to identify potential indicators from previous studies on ecosystem services and NBSs. The next step involved a validation process of the initially identified set of indicators, involving a panel of experts. This rigorous filtering made our framework practical for real-world use. After the final list was approved by reviewed by the expert panel, we moved to the final step. Here, we use the total rate of return (TRR) [17] as a performance indicator derived from the COSIMA approach. The TRR combines CBA and MCDA into a single tool. As Fig. 2 shows, this

process provides us with a clear way to calculate performance and compare different BNG scenarios. As noted above, the present methodological phase focuses on building the assessment structure, while an application will be used later to test its empirical implementation.

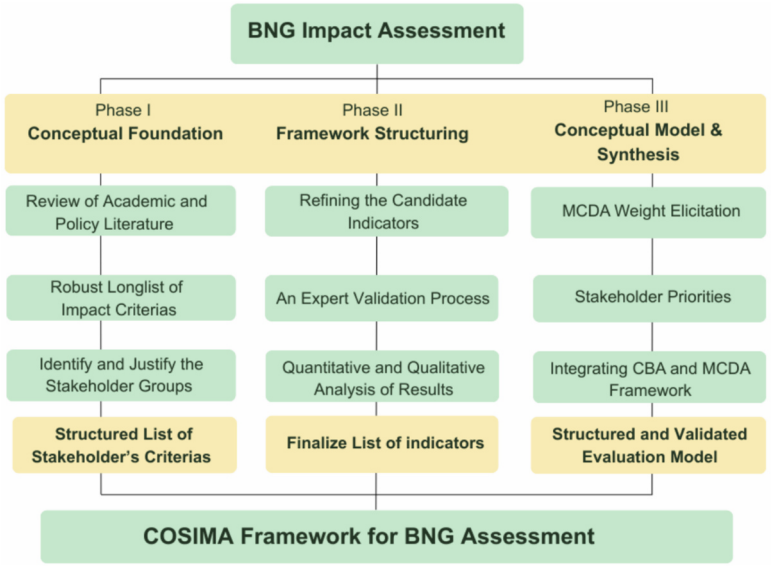

Fig. 2. Three-phase research workflow for COSIMA development.

3.2 Stakeholder Analysis

As mentioned above, the first step of the framework involves SA. In this phase, we identify the main actors affected by BNG decisions and consider how their different interests and values can be represented in the assessment framework [16]. This is important for identifying the set of indicators in the first place. But it is also relevant for the application of the MCDA, which seeks to capture real, intangible, and extra-economic priorities and trade-offs, rather than simply considering monetary aspects. This way, we can obtain a more complete picture and consider aspects that would otherwise be excluded by applying CBA alone.

To identify stakeholders, we relied on two existing frameworks. First, the NECR502 assessment plan [29] groups actors based on their proximity to the project. "Primary" stakeholders, such as developers and planning authorities, have legal responsibilities. "Direct" stakeholders, such as ecologists and contractors, are responsible for technical execution. Finally, "indirect" actors, including universities and civil society, shape the broader policy debate. We combined this insight with the BNG and ENG stakeholder map [30]. This second tool tracks who is involved at each stage of a project. It includes a wide range of actors, from funders and legal teams to service providers and local residents.

This mapping informed the selection of the three main stakeholder perspectives later discussed in Sect. 4.1.

3.3 Indicator Selection Process

To better understand how the BNG policy works, we examined policy documents, technical guidance, and grey literature reports, including materials from Natural England and the Green Finance Institute. We used this information to select several key indicators for the next stage that would demonstrate the policy's effectiveness. These indicators are important because they help us understand whether the policy is having the desired impact against its objectives. By analyzing both academic research and practical aspects, we can gain a more complete picture of the policy's performance.

In parallel, a systematic review of the scientific and academic literature was conducted. The database used in this preliminary analysis phase was ScienceDirect, updated in August 2025, based on ten Boolean search queries predefined by the authors. Following the PRISMA-ScR protocol, the initial search yielded 3,259 results. These were subsequently refined through a multi-stage filtering process based on English language, document type, journal articles only, and a publication period defined between 2020 and 2025. We cleaned the search results by eliminating duplicates and analyzing titles and abstracts. This led to 23 relevant products. A matrix including authors, title, evaluation methodology (monetary and non-monetary), and indicators used was created to gather all the information. From this selection, we extracted specific indicators directly from 18 articles that explicitly reported assessment criteria or measurable indicators, creating an initial list. Then, we began filtering. We combined the overlapping ideas and eliminated anything that was difficult to measure ex ante (before a project begins). Ultimately, we arrived at 26 practical indicators, grouped by stakeholder and dimension.

3.4 Expert Review Procedure

To assess the relevance, clarity, and practical applicability of the indicators to be included in the model, we asked a panel of experts to review them. We selected individuals with a combination of academic research in decision support and practical experience in the public and private sectors in environmental assessment. This validation was conducted in two phases. First, the experts rated each indicator on a scale of 1 to 5 in terms of relevance and clarity, using a Likert scale. This allowed us to initially determine whether the selected indicators were meaningful and aligned with the objective. They also provided feedback and comments, which we used to simplify and refine the list. Once the indicator list was refined, the same panel weighted the MCDA criteria. The method used was the 100-point method. In detail, experts allocated 100 points across the MCDA indicators within each stakeholder category, according to their professional judgment. This approach supports transparency in the validation process and provides an initial consolidation of the model, although the results remain limited by the small size of the expert panel.

3.5 The COSIMA Framework

CBA handles financial data well. It easily tracks investment costs, maintenance, and monetizable ESs. However, it does not account for social and environmental values that do not have a direct market price. COSIMA solves this problem by integrating CBA parameters with a multi-criteria analysis module based on multi-attribute value theory (MAVT). COSIMA allows for the aggregation of monetary and non-monetary performance by calculating the total rate of return (TRR) for each alternative A_k using Eq. 1:

$$TRR(A_k) = \frac{TV(A_k)}{C_k} = \frac{1}{C_k} \cdot \left[\sum_{1=1}^{n} V_i(X_{ik}) + \alpha \cdot \left(\sum_{j=1}^{m} w_j \cdot V_j\left(Y_{jk}\right) \right) \right] \quad (1)$$

where A_k represents the specific project option under review. $TV(A_k)$ stands for its Total Value, which gathers all the benefits together. On the expense side, C_k tracks the Total Cost. This includes both the upfront investment and 30 full years of maintenance. The next terms break down the actual benefits. $V_i(X_{ik})$ calculates the Net Present Value for everything that has a strict financial price (the CBA impacts). On the extra-economic side, $V_j(Y_{jk})$ provides the score for a specific non-monetary criterion j, while w_j is the exact weight our experts assigned to that goal. Before aggregation, the non-monetary indicators are converted into comparable value scores through criterion-specific value functions. Finally, α acts as a sliding scale. It lets us test how much the MCDA scores should influence the final result. Setting to 0% gives us a traditional financial CBA, while pushing it to 100% fully integrates both economic and social values [16, 17].

4 Stakeholder Perspectives and Indicator Validation

4.1 Core Stakeholders

Building on the stakeholder mapping described in Sect. 3.2, the COSIMA framework assesses BNG impacts from three main perspectives: developers, local authorities, and local communities. The first concerns developers, who, as the primary delivery actors, are responsible for managing upfront costs, biodiversity credits and long-term maintenance obligations extending over 30 years [7, 31].

A second perspective focuses on local authorities, whose oversight and enforcement roles are often constrained by limited institutional capacity, as well as by the need for consistent and rigorous monitoring to ensure public value [27, 32].

Finally, the framework considers the perspective of local communities, with particular attention to the distribution of social and environmental co-benefits. This includes aspects such as access to green spaces, wellbeing and the broader quality of the local environment [27, 33].

4.2 Outcomes of the Expert Review

As anticipated, an expert panel was formed to review the indicators identified in the literature and carefully selected by the authors. This panel consisted of four members

with diverse professional backgrounds, including research, national policies, and local government, each with their own area of expertise. This ensured that all aspects of BNG implementation were considered and a diverse range of perspectives were provided. The composition of this expert panel is shown in Table 1.

When the experts examined the indicators, they found that they were overall relevant, but that different groups had different priorities. For developers, the indicators focused on economic aspects, such as the cost of on-site construction and 30-year maintenance. The experts also considered off-site costs and registration fees. However, they did not consider the legal incentives to be that important, using them only when strictly necessary. Feedback on government incentives was mixed. This was because the rules for combining and adding incentives were too restrictive. Experts believed that having well-integrated policies and plans was very important, simplifying administration and contributing to environmental protection.

Table 1. Expert panel composition

Expert profile	Country	Field of expertise
Public Sector / Agency	UK	Ecology, BNG policy, monitoring & evaluation
Practitioner / Consultancy	UK	Environmental planning, local authority BNG support
Academia	Italy	Real estate evaluation, multidimensional assessment
Academia	Italy	Urban planning, green infrastructure

From the municipalities' perspective, the focus was on broader policy outcomes that had a community impact. For example, they believed that preventing flooding in cities and absorbing carbon were very important because they helped cities adapt to climate change. The experts also emphasized the importance of ensuring that the actions taken aligned with local priorities. This way, the money invested would have a real impact at the local level. When they analyzed what matters to local communities, a key aspect emerged. The experts interviewed stated that being in contact with nature is good for both the body and the mind. They believe that ensuring everyone has access to these benefits is essential to creating equity, which is what we mean by environmental justice.

4.3 Resulting Indicator Set

Following the preliminary expert-informed validation, the initial indicators were refined by cross-referencing the Likert-scale ratings and feedback with the MCDA weights. This step distinguished between core indicators valid for all cases and context-dependent indicators specific to certain implementation scenarios. Furthermore, four new indicators were proposed and discussed with the experts: Ecosystem Services Provided (C5), Protected Species and Sites (C6), Nature Recovery and Ecological Connectivity (C7), and Local Planning System Capacity (C8). These indicators were added to better capture ecological quality, access to nature, and institutional capacity, which emerged as important dimensions during the expert review. The resulting indicator set, organized by

stakeholder and dimension, is shown in Tables 2, 3 and 4. Some data sources reported in these tables refer to their potential use in a future Italian application of the framework, specifically in the City of Turin, and are included to illustrate transferability rather than to report empirical results.

Table 2. Developer related indicators for COSIMA BNG assessment.

ID	Indicator	Dim.	Type	Main Data Source	Unit
B1	Cost of BNG Delivery (On-site)	Eco	CBA-Cost	DEI – Construction Cost Manuals; Regional Price Lists; City of Turin – Public Works Department	€/m^2, €/tree, €/unit
B2	Cost of BNG Delivery (Off-site)	Eco	CBA-Cost	ISPRA – Land Consumption & Restoration Reports; LIFE Projects Database	€/ha or €/m^2
B3	Statutory Biodiversity Credit Price	Eco	CBA-Cost	Credit prices from analogous environmental markets (e.g., carbon) or engineering cost estimates	€/unit
B4	Site Registration Fee	Eco	CBA-Cost	Regional / Municipal administrative fee lists (SUAP, VIA, VINCA)	€/application
B5	Maintenance Cost (30-year)	Eco	CBA-Cost	DEI – Maintenance Cost Manual; City of Turin – Green Plan / Contracts	€/m^2/year or €/tree/year (NPV 30 yrs)
B6	Government Incentives / Subsidies	Eco / Gov	CBA-Benefit	MASE – Funding and Incentive Programs; PNRR – Mission 2; LIFE and PSR grants	€/project or grant
B7	BNG Uplift Ambition	Env	MCDA-Criterion	% net gain above statutory 10% minimum; scored on expert-validated scale	% biodiversity net gain
B8	Policy / Plan Congruence	Gov	MCDA-Criterion	Qualitative alignment with Local Plans and national policy frameworks	Performance scale

Note: Dim. stands for Dimension. The dimensional abbreviations used are: Eco (Economic), Env (Environmental), Gov (Governance), Soc (Social), Cul (Cultural), and Hea (Health).

Table 3. Municipality related indicators for COSIMA BNG assessment.

ID	Indicator	Dim.	Type	Main Data Source	Unit
C1	Urban Flood Risk Mitigation	Env	CBA-Benefit	Hydrological models; damage cost databases	€ (from m^3 retained)
C2	Carbon Sequestration	Env. / Eco	CBA-Benefit	EU ETS / Voluntary Carbon Markets; DEI – Green Works / Ecological Engineering	€/tCO_2e or €/ha habitat creation
C3	Achievement of Strategic Policy Targets	Gov	MCDA-Criterion	% of policy objectives achieved; scored against policy documents and project reports	% achievement; Score [1–3]
C4	Job Opportunities	Soc / Eco	MCDA-Criterion	Quantitative count of employment opportunities created; expert-validated scale	no. jobs created
C5	Ecosystem Services Provided	Env. / Eco	MCDA-Criterion	Composite qualitative score of ES bundle delivered; expert-weighted criterion	Performance scale
C6	Protected Species / Sites	Env	MCDA-Criterion	Qualitative assessment of contribution to protected species recovery; ecologist expert score	Performance scale
C7	Nature Recovery and Ecological Connectivity	Env	MCDA-Criterion	GIS Connectivity Analysis	Landscape Connectivity Index; Score [1–3]
C8	Local Planning System Capacity	Gov	MCDA-Criterion	Qualitative assessment of LPA administrative and monitoring capacity	Performance scale

Note: Dim. stands for Dimension. The dimensional abbreviations used are: Eco (Economic), Env (Environmental), Gov (Governance), Soc (Social), Cul (Cultural), and Hea (Health).

Table 4. Local community related indicators for COSIMA BNG assessment.

ID	Indicator	Dim.	Type	Main Data Source	Unit
D1	Property Value Uplift	Eco	CBA-Benefit	Academic literature (WTP, Travel Cost); Real estate data	€/m^2 or % uplift

(*continued*)

Table 4. (*continued*)

ID	Indicator	Dim.	Type	Main Data Source	Unit
D2	Urban Cooling (Heatwave Mitigation)	Eco	CBA-Benefit	Microclimate models; energy price data	€ energy savings from Δ°C reduction
D3	Recreation Value	Soc / Cul	CBA-Benefit	Academic literature (WTP, Travel Cost)	€/visit or €/year
D4	Access to Green Space	Soc / Hea	MCDA-Criterion	GIS analysis: % residents within 300 m of accessible green space; WHO benchmark scoring	% residents within 300 m
D5	Inclusion in Decision-Making	Soc / Gov	MCDA-Criterion	Procedural equity indicator; n° stakeholders engaged in weighting phase	Performance scale
D6	Social Inclusion and Cohesion	Soc	MCDA-Criterion	Proxy metrics: n° community events enabled; expert-validated scale	Performance scale
D7	Place Attachment and Cultural Identity	Cul	MCDA-Criterion	Community input or cultural mapping; qualitative score based on design documentation	Performance scale
D8	Opportunities for Social Relations	Soc	MCDA-Criterion	Design feature assessment; qualitative score based on project design documents	Performance scale
D9	Outdoor Activities	Hea / Soc	MCDA-Criterion	Diversity of outdoor uses provided; n° different activity types enabled by BNG design	no. activity types
D10	Places for Meditation and Psychophysical Well-being	Hea / Soc	MCDA-Criterion	n° dedicated spaces for quiet contemplation; quantitative count from project design	no. spaces

(*continued*)

Table 4. (*continued*)

ID	Indicator	Dim.	Type	Main Data Source	Unit
D11	Educational Activities	Soc / Cul	MCDA-Criterion	n° educational opportunities created (e.g. learning trails, school programmes)	no. opportunities
D12	Aesthetic Perception	Cul	MCDA-Criterion	Subjective aesthetic value; qualitative score based on structured expert or community assessment	Performance scale

Note: Dim. stands for Dimension. The dimensional abbreviations used are: Eco (Economic), Env (Environmental), Gov (Governance), Soc (Social), Cul (Cultural), and Hea (Health).

5 Discussion of Findings and Practical Application

5.1 Integration of COSIMA and Alternative Scenario Evaluation

The COSIMA framework enables structured comparison of alternative BNG scenarios, directly addressing the Green Book's requirements for robust options appraisal. As set out in the Green Book, public sector interventions must be assessed through a sequential process of establishing a clear Business As Usual (BAU) baseline, generating a longlist of options, and conducting detailed shortlist appraisal to identify the preferred approach that optimizes public value [13]. In practical terms, COSIMA requires the comparison of at least two scenarios: a baseline or BAU scenario, representing the existing condition, and a project scenario, representing the proposed intervention. Further BNG delivery options can then be added as alternative scenarios. COSIMA makes these requirements assessable in the BNG context by providing a unified framework capable of evaluating multiple scenarios, against a common set of validated indicators. To illustrate this potential use, a local planning authority could compare the existing condition with a proposed biodiversity-enhancement scenario and, where relevant, with additional BNG delivery options such as on-site habitat creation, off-site compensation, or credit purchase. In a future application of COSIMA, the authority could calculate a TRR for each alternative by monetising CBA indicators and scoring MCDA criteria using the expert-informed indicator set. The resulting TRR scores could provide a transparent, evidence-based basis for selecting the preferred option, making explicit the trade-offs between financial efficiency and broader ecological and social value. At the core of this capability is the TRR formulation, which integrates CBA with MCDA analysis, by aggregating stakeholder-weighted indicators into a composite score.

The expert validation process strengthens the credibility of the framework, while the variation in MCDA weights assigned by individual experts reflects the genuine plurality of values that characterise BNG decision-making [34, 35].

A recognised sensitivity of MCDA-based frameworks concerns the influence of stakeholder weighting choices on final results. Within COSIMA, different stakeholder groups are likely to assign different weights reflecting their distinct priorities, which will in turn produce different TRR scores for the same project alternative. Future applications of COSIMA could incorporate formal sensitivity analysis by systematically varying the α parameter and stakeholder weights to observe how TRR rankings respond under different value assumptions.

By revealing these tensions explicitly, COSIMA supports more informed and defensible option selection, providing public authorities with a transparent basis for negotiation between stakeholders with divergent priorities [35] and directly operationalising Green Book principles for evidence-based appraisal.

5.2 Policy Implications

COSIMA addresses a clear need for rigorous, transparent appraisal tools as mandatory BNG requirement is progressively adopted.

For local planning authorities, it provides a practical and evidence-based tool to evaluate developer proposals against validated set of ecological, social, and economic indicators. This strengthens the technical credibility of planning decisions.

Beyond its technical function, COSIMA framework also creates a space for structured dialogue between stakeholders. This dialogue is particularly important when interpreting indicators such as property value uplift. Although this indicator is included as a potential economic benefit for local communities, it should not be read as an unqualified positive outcome. In some urban contexts, environmental improvements and new green infrastructure may contribute to green gentrification, increasing property values and living costs and potentially reducing the ability of vulnerable residents to remain in the area [36, 37]. For this reason, COSIMA should support not only the identification of aggregate benefits, but also a discussion of their distribution across different social groups.

6 Conclusion and Future Perspectives

6.1 Summary of Contributions

The main contribution of this research is the integration of CBA and MCDA in the context of BNG. An additional contribution of this study is the systematic development and preliminary expert-informed validation of a comprehensive set of indicators. The framework is grounded in a three-phase methodology that integrates a grey literature review, a systematic analysis of academic sources, stakeholder analysis, and expert validation. Finally, the expert review provided an initial assessment of the relevance, clarity, and practical usefulness of the indicators for the ex ante evaluation of BNG impacts.

6.2 Limitations

This study has limitations, which clearly indicate some areas where further exploration is needed. First, the validation process involved a small panel of four specialists covering

fields such as ecology, environmental economics, urban planning, and conservation. While they provided a good starting point, such a small group may represent a limited perspective. Therefore, the expert validation should be interpreted as preliminary and not statistically representative. To make our research more robust and inclusive, we will need to expand this group in the future and organize workshops to gather input from a broad range of stakeholders. Another limitation of our study is that we considered only practically measurable indicators. This excluded some complex variables, such as the cultural benefits of ecosystems or the equitable distribution of benefits among different groups. These values, often considered intangible, are difficult to quantify, whether on a monetary or qualitative scale, which made it difficult to include them in our framework. The framework also does not consider some long-term impacts, such as the influence of BNG on climate resilience, as these effects may emerge after the standard 30-year maintenance period. Future research should address these missing dimensions and explore how they can be integrated into the framework. A further limitation is that the framework does not include a specific indicator for green gentrification risk. While property value uplift is considered as a possible benefit, higher property values may also have negative effects, especially if they increase housing costs or make it harder for vulnerable residents to remain in the area. Future research should therefore explore how this risk can be considered in ex-ante evaluation.

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