Politecnico di Torino

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Territorial, Urban, Environmental, and Landscape Planning

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"Implementing Biodiversity Net Gain 10%: A Decision-Making Tool for Evaluating Alternative Projects in Public Administration"

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Abstract

Biodiversity Net Gain (BNG), introduced in England as a mandatory planning requirement to reverse biodiversity loss and mobilize private investment in nature, represents a paradigm shift in environmental planning. However, as a new policy, its multi-dimensional impacts on key stakeholders in its implementation stage could vary and create new and not fully discovered impacts after its implementation. This variation of impacts, in some cases, can result in not succeeding in the aim of the policy, so understanding these impacts to better inform policymakers is necessary. There is a great need for a holistic assessment framework to evaluate the policy's true effectiveness, balance the inherent trade-offs, and optimize its implementation for both biodiversity and societal outcomes.

This research is aimed at developing and validating an integrated and comprehensive model to capture all the complexity of this policy. The COSIMA (COmposite SIgnificance and Multicriteria Assessment) framework is a new decision-making tool designed to evaluate the impacts of BNG that integrates Cost–Benefit Analysis (CBA), Multi-Criteria Decision Analysis (MCDA) and a Total Rate of Return (TRR) indicator. The research adopts a mixed-methods design structured in three phases. First, a stakeholder analysis identifies developers, government and local communities as the core perspectives for the model. Second, a dual-stream indicator selection process combines an exploratory review of policy and grey literature with a systematic scoping review of academic studies, generating and refining a multi-domain set of environmental, economic, social and governance indicators. Third, a structured expert questionnaire validates these indicators using Likert-scale importance ratings and derives MCDA weights through a 100-point allocation procedure, which are then embedded in the COSIMA TRR.

Results reveal a clear hierarchy of priorities across stakeholder groups. Experts emphasise delivery and long-term maintenance costs for developers, risk reduction and ecosystem service benefits for government, and socio-economic and health-related co-benefits for communities. The thesis concludes that COSIMA provides a transparent and flexible tool for ex-ante appraisal of BNG-type interventions, providing public administrators and policymakers with a critical evidence-based tool to guide decision-making, foster transparent stakeholder dialogue, and ultimately optimize the BNG policy to ensure it delivers on its promise of sustainable development and meaningful nature recovery.

Keywords: Biodiversity Net Gain (BNG), Environmental Policy Evaluation, Multi-Criteria Decision Analysis (MCDA), Cost-Benefit Analysis (CBA), Stakeholder Analysis, Sustainable Development, COSIMA Framework.

To the memory of my grandfather,

Mohammad Ali Amirkhani

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Abbreviations

BBOP – Business and Biodiversity Offsets Programme

BNG – Biodiversity Net Gain

CBA – Cost-Benefit Analysis

CBD – Convention on Biological Diversity

CEA – Cost-Effectiveness Analysis

CIEEM – Chartered Institute of Ecology and Environmental Management

COSIMA – COmposite SIgnificance and Multicriteria Assessment

DEFRA – Department for Environment, Food and Rural Affairs

EIA – Environmental Impact Assessment

EIP – Environmental Improvement Plan

ENG – Environmental Net Gain

GBF – Global Biodiversity Framework

GI – Green Infrastructure

HRA – Habitat Regulations Assessment

IUCN – International Union for Conservation of Nature

LNRS – Local Nature Recovery Strategies

LPA – Local Planning Authority

MAVT – Multi-Attribute Value Theory

MCDA – Multi-Criteria Decision Analysis

MH – Mitigation Hierarchy

NBS – Nature-Based Solutions

NNL – No Net Loss

NPPF – National Planning Policy Framework

NPV – Net Present Value

NSIP – Nationally Significant Infrastructure Project

PEA – Preliminary Ecological Assessment

PIR – Post-Implementation Review

PRISMA-ScR – Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews

SBM – Statutory Biodiversity Metric

SDG – Sustainable Development Goals

SEA – Strategic Environmental Assessment

SEEA EA – System of Environmental-Economic Accounting Ecosystem Accounting

SMART – Specific, Measurable, Achievable, Relevant, Time-bound

SSM – Small Sites Metric

TRR – Total Rate of Return

UKGBC – UK Green Building Council

WHO – World Health Organization

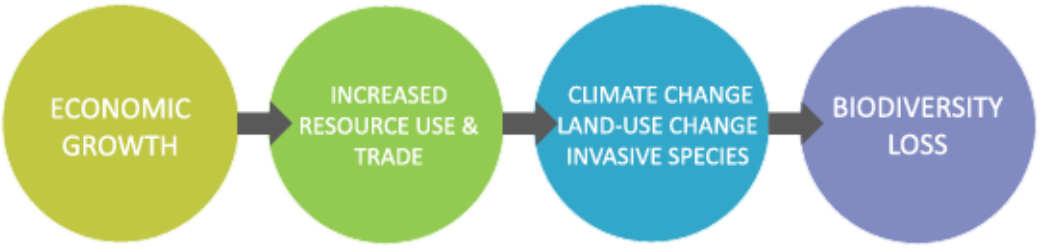
Chapter 1: Introduction

1. Introduction

1.1. Background

1.1.1. Biodiversity Loss and Development Pressures

Economic growth contributes to biodiversity loss through increased consumption of resources, land-use change, greenhouse gas emissions, and the global spread of invasive species. These pressures cause widespread habitat destruction, fragmentation, and pollution, leading to severe declines in species populations and ecosystem health worldwide (Otero et al., 2020)



Figur1.Pathways linking economic growth to biodiversity loss through increased resource use, (Otero et al., 2020)

England is among the most nature-depleted countries in the world, with centuries of agricultural intensification, urban expansion, and infrastructure development contributing to widespread habitat loss and degradation (DEFRA, 2023b). The Biodiversity Intactness Index shows that only about 42% of the UK's original biodiversity remains, well below the European average of 83.7%, placing the UK among the most ecologically degraded in Europe This decline threatens not only wildlife but also the vital ecosystem services that underpin human well-being, including pollination, carbon sequestration, and recreational spaces (UK Green Council Building, 2023).

In response, the UK government has established legally binding targets to halt species decline and promote nature recovery by 2030, enacted through the Environment Act (2021) and supported by strategies such as the mandatory Biodiversity Net Gain (BNG) policy and the Environmental Improvement Plan 2023 (CIEEM, CIRIA, 2016).

1.1.2. Biodiversity Net Gain and its Mandatory Implementation in England

Biodiversity Net Gain (BNG) is a new planning policy (Webster et al., 2023) and an approach to development and land management that ensures biodiversity is left in a measurably better state than it was before the development. Introduced through the Environment Act 2021, a minimum of 10% increase in biodiversity value became a mandatory requirement in England for most of new planning permissions in 2024. It aims to address biodiversity loss caused by development, by restoring or creating natural habitats and managing them for long-term ecological benefits.

To achieve this 10%, a standardized assessment tool known as the Statutory Biodiversity Metric is used to calculate biodiversity value and ensure a minimum of net gain compared to the pre-development baseline (DEFRA, 2023a)

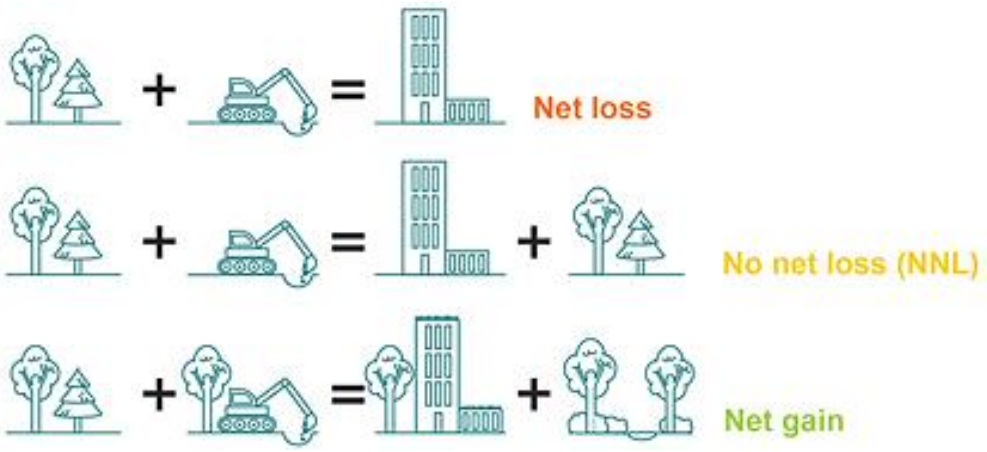


Figure 2. The conceptual framework of Biodiversity Net Gain (Fraser et al., 2024)

1.1.3. Biodiversity Net Gain in Global and National Contexts

BNG aligns with both international and national conservation ambitions. Globally, it supports the objectives of the Convention on Biological Diversity (CBD) and the United Nations Sustainable Development Goals (SDGs), particularly those targeting biodiversity loss and ecosystem restoration(Business and Biodiversity Offsets Programme, 2012; IUCN, 2016; UNDP, 2016).

BNG builds upon the earlier No Net Loss (NNL) principle, which aimed to balance the negative impacts of development by ensuring that any biodiversity losses were compensated through restoration or offsetting. While NNL sought to leave biodiversity at the same level as before development, in practice it often only mitigated harm rather than improving ecological conditions. In contrast, BNG goes a step further, it requires developments to deliver a measurable improvement in biodiversity, ensuring that nature is left in a better state than before construction. This shift from “no loss” to “net gain” reflects a more proactive approach to nature recovery, supporting the UK’s broader environmental commitments (CIEEM, CIRIA, 2016).

At the national level, BNG complements key UK policies such as the National Planning Policy Framework (NPPF), which promotes sustainable development while safeguarding the natural environment, and the 25-Year Environment Plan, which outlines long-term goals for environmental improvement. The Environment Act 2021 made BNG a legal requirement and established statutory targets for restoring habitats and reversing species decline .In essence, BNG serves as a practical mechanism to translate these high-level policies into on-the-ground action for biodiversity enhancement(CIEEM, CIRIA, 2016; Onsman & Burke, 2019).

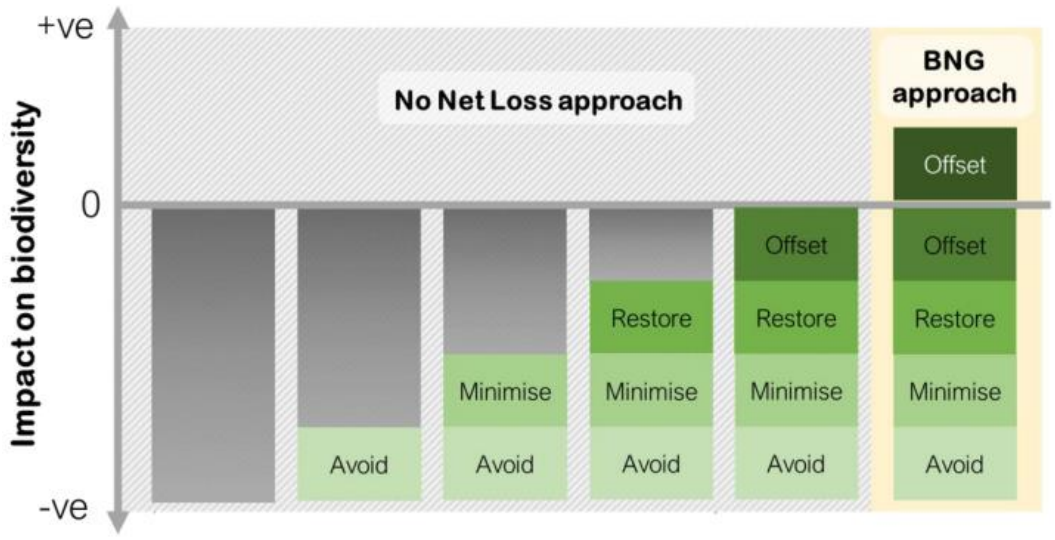


Figure 3. An illustration of difference between the previous policy of No Net Loss and new BNG approach to mitigating biodiversity loss during development (Webster et al., 2023)

1.1.3.1. Role of BNG in Sustainable Development and Global Goals

Biodiversity is essential to sustain our society and economy and enhancing biodiversity is integral to sustainable development (J. Baker et al., 2019). The concept of BNG represents a shift in how development interacts with the natural environment, ensuring that new housing, business, and infrastructure projects actively enhance biodiversity rather than merely compensating for losses. This approach supports nature-based solutions that help tackle broader sustainability challenges, including climate change mitigation, water and air quality improvement, and flood prevention (J. Baker et al., 2019; Natural England, 2024).

BNG directly contributes to several of the United Nations Sustainable Development Goals (SDGs) by integrating ecological restoration into development practice. It advances SDG 15 (Life on Land) through habitat creation and ecosystem restoration, helping to halt biodiversity loss and sustain the natural systems on which all life depends. By promoting carbon sequestration and climate resilience, it supports SDG 13 (Climate Action), demonstrating how restoring ecosystems can play a vital role in reducing greenhouse gas emissions and adapting to a changing climate. At the same time, BNG fosters greener, more inclusive, and resilient urban environments, aligning with SDG 11 (Sustainable Cities and Communities). Through enhanced access to green spaces and improved environmental quality, it also contributes to SDG 3 (Good Health and Well-being) by supporting physical activity, mental health, and overall quality of life (Webinar on BNG and SDGs, 2023). By addressing these interconnected goals, BNG demonstrates that economic development and environmental conservation can be mutually reinforcing (CIEEM, 2021; Sustainable, 2015; UNDP, 2016)

1.1.4. Integration of BNG in Urban and Environmental Planning

The introduction of the mandatory 10% BNG has influenced urban and environmental planning in England. It introduced new legal and planning obligations, requiring local authorities, developers, and other stakeholders to adapt their strategies and plans to deliver measurable biodiversity gains(Wentworth, 2024).

1.1.4.1. Integrating BNG into Local and Strategic Planning Frameworks

Local planning authorities (LPAs) must now integrate BNG into their Local Plans. They must identify opportunities for biodiversity enhancement within their areas and include policies that support measurable net gains for nature (CIEEM, CIRIA, 2016). The integration of BNG into Local Plans aligns with the broader framework of Local Nature Recovery Strategies (LNRS), which identify priorities and actions for nature recovery in specific areas. This process is further supported by Strategic Environmental Assessment (SEA), a systematic approach to evaluating the environmental impacts of plans and policies. LNRS provide a strategic approach to habitat restoration, such as creating wetlands, planting trees, and restoring peatlands, ensuring that biodiversity gains are targeted where they will have the most impact. By aligning BNG with LNRS, local authorities can ensure that development projects contribute to the expansion of a nature recovery network, a key commitment of the government's 25-Year Environment Plan (DEFRA, 2021, 2023b)

1.1.4.2. BNG in the Planning Approval Process

This shift has also led to changes in planning and permitting processes. Local planning authorities need to review and approve Biodiversity Gain Plans submitted by developers, ensuring they meet the required standards. Biodiversity Gain Plan is a document provided by developers before construction begins, it explains how a project achieved BNG (CIEEM, CIRIA, 2016)

1.1.4.3. Embedding BNG within Environmental Assessment Systems

BNG is integrated within UK's planning assessment systems like Environmental Impact Assessments (EIA), Ecological Impact Assessments (EcIA), and Preliminary Ecological Assessments (PEA), to evaluate and mitigate the environmental effects of development projects. The EIA Regulations require projects to assess biodiversity impacts alongside other environmental factors. Similarly, EcIA, which focuses specifically on ecological impacts, supports BNG by providing baseline assessments and guiding biodiversity improvements. Local authorities must also monitor the implementation of these plans after development begins, taking enforcement action if commitments are not fulfilled (CIEEM, 2021; DEFRA, 2023b)

1.1.5. BNG Implementation Process

To implement the mandatory 10% BNG on a project, the process begins with a baseline habitat survey and condition assessment. This step, undertaken with input from ecologists and landscape architects, calculates the biodiversity value of the site before development.

The post-development biodiversity value is then assessed to ensure that any losses are compensated with habitats of equivalent or higher value, meeting the BNG targets. The process is guided by the mitigation hierarchy, which provides a structured approach for developers to avoid, mitigate, or compensate for adverse impacts on habitats. BNG can be achieved through three main pathways:

- On-site habitat creation or enhancement via landscaping, blue and green infrastructure; such as green roofs, urban tree planting, wetland restoration or sustainable drainage systems.
- When on-site improvements are insufficient or unfeasible, developers can develop habitat creation or restoration Off-site, supporting ecosystem restoration and enhance biodiversity corridors.
- If neither on-site nor off-site solutions are viable, developers can purchase statutory credits, which fund large-scale conservation and restoration projects delivering high-value green and blue habitats(DEFRA, 2023c).

1.2. Problem Statement

BNG is a policy still in its early stages of implementation. Since it is new and its impacts are diverse across different stakeholder groups, there is a critical need for a tool to comprehensively assess its multi-dimensional effects and the trade-offs between them. While BNG aims to enhance biodiversity through development, its implementation presents a complex mix of challenges and opportunities for developers, local communities, and government authorities that require a systematic evaluation.

The absence of a holistic assessment methodology makes it difficult to understand the policy's true effectiveness and utility. Therefore, the primary aim of this study is to develop a comprehensive model for evaluating BNG impacts across the core stakeholder groups. The impact assessment model will be designed to clarify the trade-offs inherent in the policy's application and provide an evidence-based foundation for its future improvement.

1.2.1. Developer Responsibilities and Burdens

For developers, BNG has introduced new responsibilities and compliance costs, including the preparation and approval of biodiversity gain plans, securing long-term management agreements, and adhering to legal obligations to avoid penalties (F. Baker, 2025; CIEEM, CIRIA,

2016). These additional requirements raise concerns about the financial and administrative burden on the private sector. However, before the policy became mandatory, Defra suggested that BNG could also generate benefits, such as higher property values, reduced legal risks, and long-term financial incentives (Knight-Lenihan, 2020) .

1.2.2. Institutional Constraints and Policy Potential

From a governance perspective, BNG has been shaped within a neoliberal economic context that emphasizes privatized conservation and reduced public expenditure. Under this system, local councils are expected to deliver biodiversity outcomes with limited resources. This has led to two major concerns affecting BNG's effectiveness.

Weakened monitoring and enforcement: Limited funding reduces the capacity of local authorities to evaluate biodiversity outcomes and ensure compliance (Knight-Lenihan, 2020)

Reduced community participation: Budget constraints make it difficult to engage residents and incorporate local knowledge, leaving communities feeling excluded from decision-making (CIEEM, n.d.; Taherzadeh & Howley, 2018)

Despite these challenges, BNG has the potential to create long-term social and economic benefits. By supporting nature-based solutions, such as improving air and water quality, reducing flood risk, and mitigating heat, it can enhance urban resilience and reduce pressure on public infrastructure and emergency services(Ministry of Housing, Communities and Local Government and Department for Levelling Up, 2024; Raymond et al., 2017). These outcomes could ultimately lead to financial savings for the government, an aspect this study aims to explore.

1.2.3. Environmental, Socio-economic Outcomes of BNG

Recent research by Balfour Beatty, the University of Oxford, the Durrell Institute of Conservation and Ecology (DICE), and CIEEM highlights that well-designed BNG projects can support the Sustainable Development Goals by improving access to high-quality green spaces, enhancing well-being, and fostering healthier environments (CIEEM, 2021) Exposure to green spaces has been shown to reduce stress, improve mood, and encourage physical activity (WHO Regional Office for Europe, 2016). However, if poorly implemented, BNG could unintentionally restrict access to nature, for example when off-site compensation creates habitats far from affected communities or when rising property values lead to green gentrification and the displacement of low-income residents (Taherzadeh & Howley, 2018)

1.3. Research Question

This research is framed by the development of an assessment model for BNG impactevaluation. It will investigate the implementation of the BNG policy and its implications on three key areas

of stakeholder impact, benefits and externalities, and policy effectiveness. Each area addressing specific research questions.

1.3.1. Stakeholder Impact

Research Question: How can an assessment model be structured to systematically capture and compare the distinct impacts of BNG implementation on key stakeholders, including developers, local communities, and government authorities?

BNG introduces new responsibilities and compliance requirements for developers, influencing project costs, timelines, and management practices. For local authorities, it adds regulatory and monitoring obligations, while local communities experience both the benefits of improved environments and the challenges that arise from changes in access to green spaces. Understanding these varying perspectives is essential to assess how effectively BNG delivers balanced outcomes across stakeholder groups.

1.3.2. Benefits and Externalities

Research Question: What positive and negative externalities emerge from BNG implementation? And what set of indicators and valuation methods can be integrated effectively measure them?

Delivering BNG can lead to direct ecological benefits such as improved biodiversity, enhanced habitats, greater species diversity, and more resilient ecosystems that support essential services like pollination, soil health, and water purification. Indirect positive effects include increased climate resilience, reduced flood risks through green infrastructure, higher property values, and improved public health and well-being. However, BNG can also produce negative externalities, such as added costs and regulatory burdens for developers, and unequal access to green spaces for local communities. Examining these outcomes provides a comprehensive view of how BNG shapes both environmental and social systems.

1.3.3. Policy Optimization

Research Question: How can BNG policies be optimized to ensure better biodiversity and societal outcomes?

By analyzing the interactions between stakeholders, benefits, and externalities, this research aims to identify opportunities for improving BNG's design and delivery. The goal is to ensure that the policy not only strengthens biodiversity conservation but also supports fair, inclusive, and sustainable development across different communities.

1.4. Research Objectives

The primary aim of this research is to investigate on BNG impacts and developing a comprehensive evaluation framework for it. This aim is achieved through three specific objectives:

1.4.1. Identifying Key Stakeholders and Their Roles

This objective aims to map the main actors involved in the implementation of BNG. It also seeks to examine their respective responsibilities, and challenges in achieving biodiversity enhancement through development projects.

1.4.2. Assess Impacts and Outcomes of BNG

The second objective focuses on analyzing how BNG affects different stakeholders, considering both opportunities and barriers in its implementation. It aims to identify measurable ecological, economic, and social indicators that capture the short-term and long-term impacts of BNG, including its benefits and externalities.

1.4.3. Develop an Evaluation model for BNG Assessment

The final objective is to design and propose COSIMA as a comprehensive framework for assessing the impacts of BNG. This framework will integrate analytical tools such as Cost-Benefit Analysis (CBA) for economic evaluation, Multi-Criteria Decision Analysis (MCDA) for capturing stakeholder perspectives, and a Total Rate of Return (TRR) model for evaluating overall outcomes across environmental, social, and economic dimensions.

1.6. Thesis Structure

This thesis is organized into five chapters that collectively aim to deepen the understanding of BNG and to develop an integrating evaluation framework for BNG. Each chapter builds progressively from conceptual foundations to empirical application and policy interpretation.

Chapter 1: Introduction

This chapter introduces the BNG policy and its relevance to biodiversity conservation and sustainable development. It outlines the research problem, questions, and objectives, and explains the overall structure of the thesis.

Chapter 2: Literature Review

This chapter examines existing research on BNG, biodiversity policies, and environmental evaluation methods. It reviews:

- The evolution of biodiversity compensation policies, from international frameworks (e.g., CBD) to the UK's mandatory BNG.

- Core principles underpinning BNG, including the Mitigation Hierarchy and the transition from No Net Loss (NNL).
- Key challenges in BNG implementation, such as governance, monitoring, and financial considerations.
- Current evaluation approaches, including applications of CBA and MCDA in biodiversity and ecosystem assessment, analyzing their strengths and limitations to justify their integration.
- The chapter concludes by identifying knowledge gaps that justify the need for this research.

Chapter 3: Methodological Framework (Model Development)

This chapter details the conceptual and procedural methodology for designing the COSIMA model. It provides a comprehensive description of:

- The overall research design and analytical logic, explaining the rationale for a mixed-methods approach and the integration of CBA, MCDA, and the Total Rate of Return (TRR).
- The stakeholder analysis methodology, explaining why this phase is essential and how the key stakeholder groups were identified based on authoritative policy sources (NECR502 and Defra).
- The indicator selection process, detailing the dual-stream review (systematic scoping review and policy analysis) for identifying, screening, and classifying candidate indicators by stakeholder domain.
- The expert validation and weighting procedure, outlining the design of the validation survey, the composition of the expert panel, and the methods for eliciting indicator ratings and MCDA weights.

Chapter 4: Framework Structuring and Validation (Conceptual Application)

This chapter presents the results of the framework construction and its conceptual validation. It translates the methodological steps from Chapter 3 into tangible outcomes, including:

- The results of the stakeholder analysis, presenting the final, justified grouping into Developers, Government, and Local Communities.
- The results of the literature review, showcasing the candidate set of indicators derived from the dual-stream process and structured for expert validation.
- The results of the expert questionnaire, reporting the validated indicator set, the derived MCDA domain weights, and descriptive statistics from the validation process.
- A quantitative synthesis of findings, using graphical representations to illustrate the expert-derived weighting structure and indicator rankings.

- The final structured COSIMA framework, presenting the complete, validated model with its integrated CBA-MCDA-TRR architecture, ready for empirical application.

Chapter 5: Discussion and Conclusion

The final chapter synthesizes the research journey, examining the theoretical contributions and practical implications of the developed COSIMA framework. It interprets the key findings, particularly the expert-validated stakeholder priorities and indicator set. The discussion critically addresses the study's limitations and proposes concrete recommendations for BNG policy, implementation, and future monitoring. The thesis concludes by outlining promising avenues for future research, including the empirical application of the framework and further methodological refinements.

1.7. Proposed Methodological Framework for BNG Analysis

The proposed methodological framework for this study is structured into three interrelated phases, each building on the previous stage to ensure the systematic development and validation of the COSIMA assessment model. The framework outlines the process for integrating CBA and MCDA into a unified analytical tool.

Phase I – Conceptual Foundation and Component Identification

This initial phase focuses on establishing the foundational elements of the assessment model. It involves a comprehensive review of academic and policy literature to contextualize BNG and identify a robust longlist of ecological, economic, and social impact criteria. Concurrently, it identifies and justifies the core stakeholder groups for the analysis. The output of this phase is a structured library of stakeholders and a candidate set of indicators, which forms the basic input for the model.

Phase II – Framework Structuring and Expert Validation

The second phase focuses on the refinement and validation of the model's components. Candidate indicators from Phase I are reviewed, filtered, and refined, ensuring conceptual distinctiveness, ex-ante measurability, and alignment with stakeholder roles.
A structured expert validation process is conducted, involving qualitative assessments (relevance, clarity, feasibility) and quantitative scoring (Likert ratings and MCDA weight allocation). This phase produces both quantitative and qualitative analyses that shape the final structure of the evaluation model.

Phase III – Conceptual Application and Synthesis

In the final phase, the validated components are consolidated into a structured and operational evaluation model. MCDA weights are elicited, stakeholder priorities are synthesized, and CBA

and MCDA are integrated into the Total Rate of Return (TRR) formulation. This phase produces a conceptually complete version of the COSIMA framework, illustrating how the integrated model captures value trade-offs, stakeholder-specific outcomes, and the multi-dimensional performance of BNG interventions.

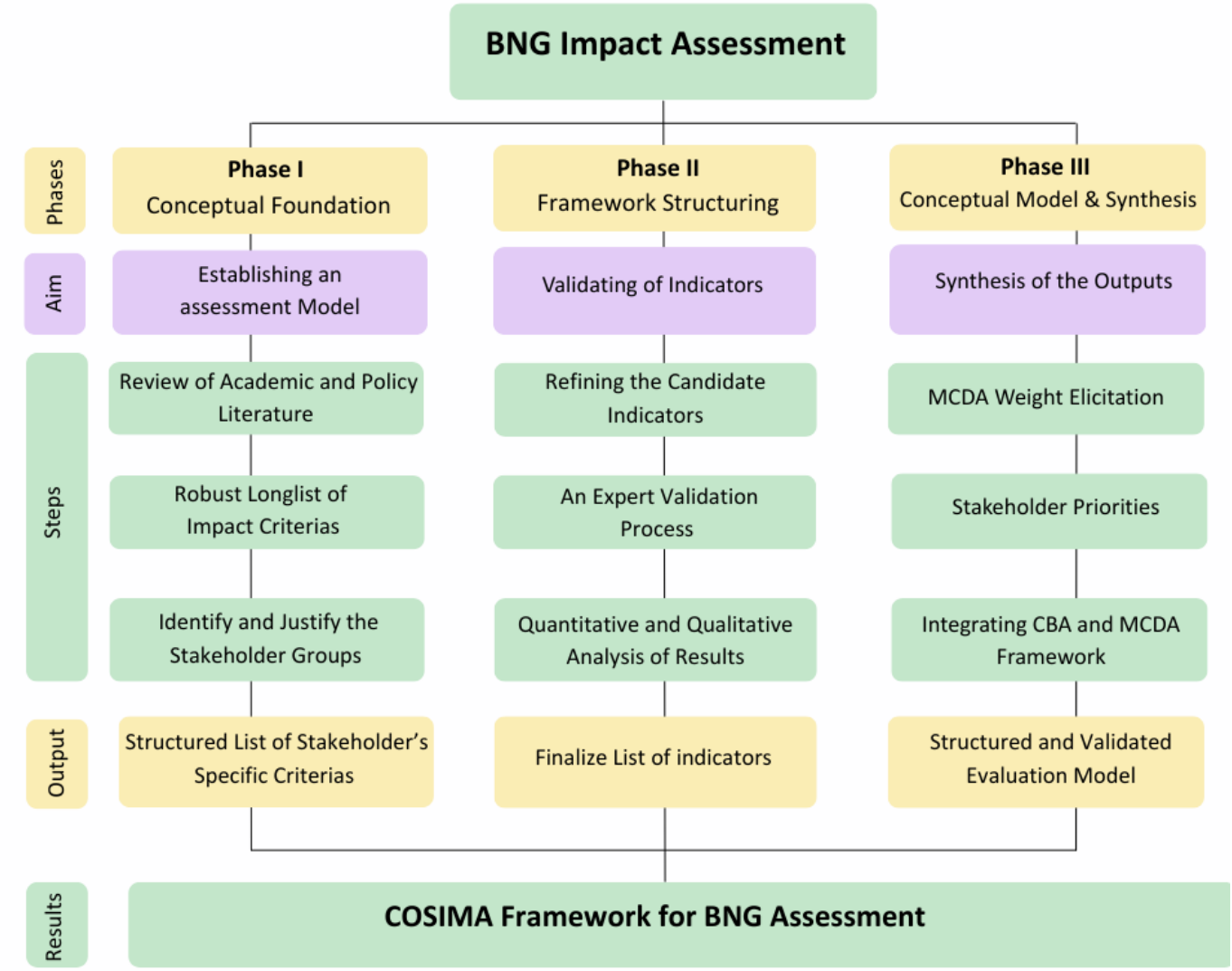


Figure 4. Thesis Structure and Workflow, Author

Chapter 2: Literature review

2. Literature review

This chapter provides a comprehensive review of the evolution of biodiversity compensation policies, from international frameworks to the UK's BNG mandate. It then delves into the core principles of NNL and the Mitigation Hierarchy that underpin BNG. Finally, it examines existing methods for evaluating environmental policies.

2.1. The Global to National Policy Evolution of Biodiversity Compensation

2.1.1 Global Frameworks for Biodiversity Conservation

Adopted at the 1992 Rio Earth Summit, the Convention on Biological Diversity (CBD) represents the first global treaty to address biodiversity conservation holistically. As a legally binding instrument, it establishes three core objectives:

1. conservation of biological diversity,
2. sustainable use of its components, and
3. fair benefit-sharing from genetic resources.

The convention's comprehensive framework addresses biodiversity at all levels of ecosystems, species and genetic diversity. In fact, it covers all possible domains that are directly or indirectly related to biodiversity and its role in development, ranging from science, politics and education to agriculture, business, culture and much more (CBD, 1992).

The CBD explicitly links biodiversity to sustainable development, noting that "biodiversity is essential for sustainable development". CBD in its overall objective encourages to actions with its Strategic Plan for Biodiversity 2011–2020 and Aichi Biodiversity Targets, which is a set of 20 targets to address the drivers of biodiversity loss, safeguard biodiversity, and promote its sustainable use by 2020, providing a framework for national action (CBD COP13, 2016).

However, the Aichi Biodiversity Targets failed to halt global biodiversity loss, because most parties did not establish effective national targets, while inadequate investments, knowledge gaps, and weak accountability mechanisms undermined implementation (Xu et al., 2021). In direct response, governments are negotiating the Post-2020 Global Biodiversity Framework (GBF), aiming to reverse biodiversity decline by 2030 and achieve recovery by 2050 through urgent, integrated actions (Leadley et al., 2022)

2.1.2 The EU Biodiversity Strategy to 2020: Regional Foundations for Net Gain

The EU Biodiversity Strategy to 2020, adopted in 2011, was a key regional response to the global targets established under the CBD. Its aim was to halt biodiversity loss within the EU and restore ecosystems by 2020 through six priority targets, including improved implementation of EU nature legislation, sustainable land use practices, and enhanced ecosystem service valuation (European Commission, 2011). A pivotal aspect of the strategy was its emphasis on mainstreaming

biodiversity into sectoral policies, such as agriculture, forestry, and spatial planning. This approach laid the essential groundwork for practical mechanisms like biodiversity offsets and net gain principles. Although progress toward the 2020 goals was limited, the strategy played a formative role in shaping the EU's support for no net loss policies and directly informed early BNG pilot efforts in the UK (DEFRA, 2021).

2.1.3 The Rise and Critique of Market-Based Mechanisms

The conservation of global biodiversity alongside economic development is a key challenge for the 21st century. The development of market-based mechanisms like biodiversity offsets emerged as a response to reconcile conservation with economic development (Bull et al., 2013). The Business and Biodiversity Offsets Programme (BBOP), launched in 2004, became a leading proponent of this approach, defining offsets as 'measurable conservation outcomes compensating for residual biodiversity impacts after avoidance and mitigation'. BBOP's principles emphasized No Net Loss or a Net Gain of biodiversity, seeking to quantify these outcomes through standardized habitat and species-based metrics (BBOP, 2013). Biodiversity offsets offer an approach that links conservation with industry, potentially providing improved ecological outcomes alongside development. While biodiversity offsets have been identified as a market-based mechanism capable of generating significant private-sector funding for conservation, their commodification of nature through the trading of biodiversity units as exchangeable commodities has attracted significant criticism.

These critiques are substantiated by empirical research. Bull and colleagues (2013) critically underscore the persistent gaps between the theory and practice of biodiversity offsetting, identifying three interrelated challenges that frequently cause schemes to fail:

1. Conceptual flaws in design: This includes a reliance on oversimplified metrics like "habitat hectares" that fail to capture biodiversity complexity, and the profound difficulty of demonstrating genuine ecological equivalence between impacted and offset sites. For instance, created wetlands are demonstrably not functionally equivalent to natural ones.
2. Implementation barriers: Compliance and monitoring are consistently weak. For example, only 30% of U.S. wetland mitigation banks met all objectives, and Canadian fish habitat offsets were tracked for just 3.7 years on average, leading to highly uncertain outcomes.
3. Development pressure and temporal mismatches: Biodiversity losses from development are immediate, while restoration gains may take decades to materialize if they succeed at all. This temporal lag, combined with the dynamic nature of ecosystems, makes the promised "no net loss" exceptionally difficult to achieve in practice (Bull et al., 2013)

In response to these documented failures, the International Union for Conservation of Nature (IUCN) adopted a precautionary policy on biodiversity offsets in 2016. This policy fundamentally reorients conservation practice away from market-based approaches like the Business and Biodiversity Offsets Programme (BBOP). While BBOP focused on standardizing measurable conservation outcomes to achieve "no net loss" (BBOP, 2013), the IUCN policy establishes stricter ecological and social safeguards, insisting offsets should only be implemented as a last resort after fully applying the mitigation hierarchy (avoid > minimize > restore > offset). The IUCN requires offsets to no net loss or net gain (IUCN, 2016).

The terms No Net Loss or Net Gain refer to the outcome achieved compared to a reference scenario. This reference scenario can be what is likely to have occurred in the absence of the project and the offset, or one that provides a better outcome for biodiversity conservation.

The IUCN mandates that offsets:

- Integrate landscape-scale conservation planning
- Respect Indigenous rights and societal values
- Apply only when all mitigation hierarchy steps have been fully considered and implemented, ecological equivalence is scientifically verifiable, and long-term governance mechanisms exist (IUCN, 2016).

This evolution from the broad aspirations of the CBD, through the market-driven approach of BBOP and its subsequent critiques, to the precautionary framework of the IUCN has cemented key principles like avoidance, no net loss, and the mitigation hierarchy as central pillars of global biodiversity conservation strategies (Droste et al., 2022)

Having established this policy context, the following sections will now introduce and define these core concepts, which fundamentally underpin modern biodiversity compensation.

2.2 No Net Loss (NNL): The Foundation of Biodiversity Compensation

While international agreements like the CBD and post-2020 GBF set ambitious biodiversity targets, their implementation hinges on practical mechanisms like No Net Loss (NNL), which is a biodiversity conservation principle that aims to ensure development projects do not result in an overall decline in biodiversity. Under NNL policies, any unavoidable ecological damage caused by a project must be fully compensated through measures such as habitat restoration, protection of existing ecosystems, or biodiversity offsets. The goal is to achieve a balance where losses at the development site are counteracted by gains elsewhere, maintaining or improving the baseline biodiversity status (IUCN, 2014).

NNL mandate that a mitigation hierarchy (MH) is applied to sequentially avoid, minimize, remediate, and offset the biodiversity impacts of new developments (Bennett et al., 2017). This

framework ensures compensation is only used after all other measures fail, reducing the risk of unjustified habitat destruction (Sharman, 2013)

2.2.1 Documented Challenges in Achieving No Net Loss

Despite its conceptual appeal, the practical application of NNL is fraught with difficulty. A global review by zu Ermgassen et al. (2019) demonstrates significant limitations in achieving NNL through biodiversity offsets, revealing:

- Variable Effectiveness by Ecosystem Type: Wetland mitigation schemes succeeded in reaching NNL goals in only half of studied cases. In contrast, forest ecosystems showed no successful NNL outcomes in any of the reviewed studies.
- Critical Implementation Shortcomings: Current methods rely heavily on oversimplified area-based metrics that fail to account for habitat quality or species composition. Enforcement remains inadequate, with compliance monitoring rates consistently below 75% across all programs.
- Systemic Weaknesses: The study identified that existing measurement tools are insufficient for comprehensive biodiversity assessment, compliance monitoring systems perform poorly, and, most significantly, there are frequent mismatches in ecological equivalence between impacted sites and their designated offsets.

The consistent failures in forest ecosystems and limited success in wetlands demonstrate that current approaches frequently fall short of delivering genuine no net loss. This evidence base underscores the urgent need for policy reforms, including the development of multidimensional biodiversity metrics, landscape-scale planning, stronger compliance mechanisms, longer-term monitoring (minimum 30 years), and clearer scientific standards for demonstrating equivalence (zu Ermgassen et al., 2019). These challenges highlight why simply aiming for 'no loss' is often insufficient, paving the way for more ambitious policies like Biodiversity Net Gain.

2.3 The Mitigation Hierarchy: Principles and Implementation

The mitigation hierarchy (MH) is a decision-making framework designed to minimize biodiversity loss from development projects by prioritizing avoidance of harm first, followed by minimization, restoration, and only as a last resort, offsetting residual impacts (BBOP, 2013; IUCN, 2016). This approach ensures that biodiversity offsets are not used to justify ecologically harmful projects or circumvent the responsibility to prevent damage. The hierarchy must be applied at both landscape/seascape and project-specific levels, integrating conservation priorities, spatial planning, and risk assessments early in development decisions (IUCN, 2016). Strict adherence to the MH is critical because no two habitats are ecologically identical, meaning

some biodiversity loss is inevitable even with offsets, making avoidance the most effective conservation strategy (Pilgrim & Ekstrom, 2014).

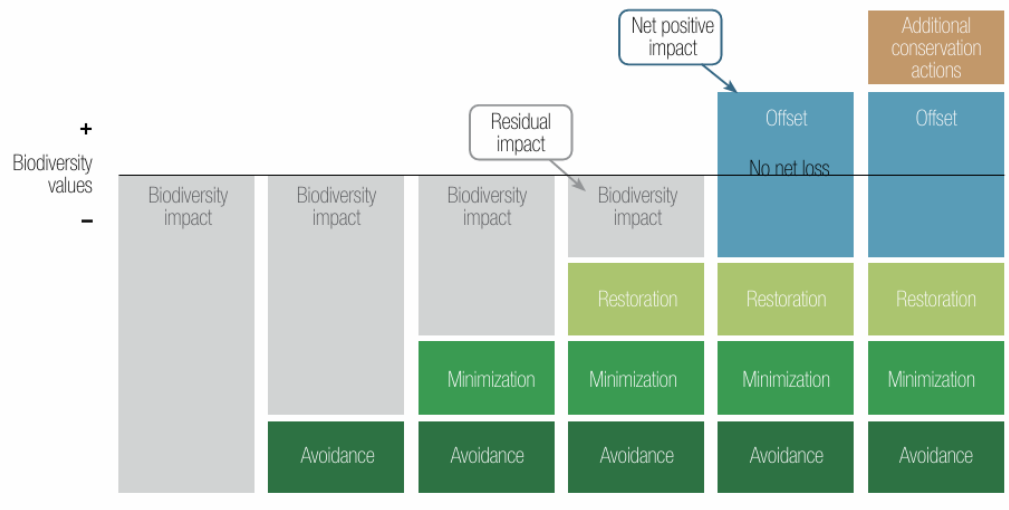


Figure 5. The mitigation hierarchy for managing biodiversity risk (IUCN, 2016).

The Four Sequential Steps of the Mitigation Hierarchy are:

1. Avoidance: The first and most critical step, which requires eliminating impacts altogether through alternative site selection, design modifications, or even abandoning projects.
2. Minimization: Where impacts are unavoidable, this step requires reducing their severity through measures like seasonal activity restrictions or technological solutions.
3. Restoration: This focuses on rehabilitating damaged ecosystems on-site to a functional state.
4. Offsetting: Only after exhausting all previous steps may offsetting be considered, and only if it delivers measurable, equivalent gains for residual impacts, with a preference for achieving a Net Gain over merely No Net Loss.

2.3.1 The Need for Policy Integration

The IUCN (2016) emphasizes the need to integrate the MH into policy and planning frameworks to improve its effectiveness. To move beyond reactive, project-by-project mitigation, IUCN recommends embedding the MH in strategic development plans and spatial decision-making. This includes designating zones where biodiversity impacts are strictly avoided and areas where offset aggregation may enhance conservation outcomes. According to IUCN, the success of the MH depends on applying precautionary and ecosystem-based approaches at every stage, ensuring that biodiversity risks are addressed proactively rather than retroactively (IUCN, 2016).

2.4 The Vital Role of Biodiversity in Sustainable Development

Biodiversity is not merely an environmental concern but a foundational pillar of sustainable development. This is explicitly recognized by the United Nations' 2030 Agenda for Sustainable Development, an ambitious and universal framework adopted by all Member States to address global societal challenges (Department of Economic and Social Affairs, 2015). Biodiversity and ecosystem services are intricately linked to numerous Sustainable Development Goals (SDGs), including SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land). Together, these links underpin human well-being, economic prosperity, and support efforts to reduce poverty and vulnerability, particularly for communities whose livelihoods depend on natural resources.

The contributions are both direct and multifaceted. Biodiverse ecosystems are central to economic activities in agriculture, forestry, and fisheries sectors that form the primary livelihood for nearly half of the global population, particularly the world's most vulnerable communities (CBD, 1992). Beyond direct resource use, biodiversity provides critical regulating services such as climate stability, water purification, and pollination, which secure the long-term viability of these sectors and human settlements. The degradation of these natural assets directly threatens progress towards the SDGs, underscoring that biodiversity loss is not only an ecological crisis but a fundamental development challenge. Consequently, policies like Biodiversity Net Gain, which mandate a measurable improvement in natural capital, can be viewed as direct operational mechanisms for achieving the intertwined objectives of the 2030 Agenda.

2.5 Biodiversity Net Gain (BNG) in the UK: A Mandatory Approach

2.5.1 Introduction and Policy Rationale

In the UK, the decline of biodiversity has been well documented, with England reported as being "largely off-track" in meeting its goal of "thriving plants and wildlife" under the 2023 Environmental Improvement Plan (EIP). In a decisive response, the UK government introduced mandatory Biodiversity Net Gain (BNG) in 2024. This policy represents a paradigm shift, legally obliging property developers to achieve not just 'no net loss' of biodiversity, but a minimum 10% net gain (Wentworth, 2024; Revenues for Nature Guidebook Series, 2024).

Operationally, BNG requires developers to quantify the pre-development ecological value of a site using a standardized statutory metric, and to submit a Biodiversity Gain Plan demonstrating how a 10% improvement will be delivered. This can be achieved through a hierarchy of measures, primarily through on-site habitat creation and enhancement, followed by off-site compensation, or, as a last resort, the purchase of statutory credits. The policy's core objectives are to:

- Contribute to national habitat and species recovery.
- Create richer natural environments for local communities.
- Generate new economic opportunities for landowners through habitat management.
- Ensure a consistent and measurable approach for developers.

By mandating a measurable net gain with 30-year monitoring, BNG moves beyond the often-elusive goal of No Net Loss and aligns with the EIP's key strategy of "mobilizing green finance and the private sector" for nature recovery (Wentworth, 2024).

2.5.2 Policy Foundations and Evolution: From NNL to BNG

The legal bedrock for BNG is the Environment Act 2021, which amended the UK's planning laws to make a biodiversity gain condition mandatory for development approval (Knight-Lenihan, 2020). This did not emerge in a vacuum but was the culmination of decades of policy evolution. Early EU directives (e.g., Birds Directive 1979, Habitats Directive 1992) established baseline protections but failed to reverse declines due to weak enforcement (DEFRA, 2021)

The transition from NNL to BNG was catalysed by critical reviews of the Environmental Impact Assessment (EIA) process, which exposed systemic failures in mitigation enforcement, funding, and monitoring (Treweek, 1995; Byron et al., 2000). The EU 2020 Biodiversity Strategy further encouraged this shift by endorsing no net loss and offsetting mechanisms. The UK's journey operationalised these concepts through a series of steps: The Natural Environment and Rural Communities (NERC) Act 2006 imposed a biodiversity duty on public authorities; Planning Policy Statement 9 (2005) encouraged enhancing biodiversity; and the 2012 National Planning Policy Framework (NPPF) explicitly demanded "net gains" where possible. Pilot offset schemes tested habitat metrics, which eventually evolved into the standardized Biodiversity Metric formalised in the Environment Act 2021.

However, this evolution is not without its critics. Scholars note that early trials revealed the impossibility of guaranteeing no net loss, and the policy's market-based, neoliberal framing risks the commodification of nature without ensuring genuine ecological equivalence (Knight-Lenihan, 2020).

2.5.3 Integration with Existing Planning and Environmental Policy

It is critical to understand that BNG operates as a supplementary layer within the UK's existing robust framework of environmental protections. It works in addition to, not in replacement of, obligations under:

- The National Planning Policy Framework (NPPF).
- The Wildlife and Countryside Act 1981.
- The Conservation of Habitats and Species Regulations 2017.
- Protections for designated sites, protected species, and irreplaceable habitats.

Furthermore, the BNG process runs parallel to requirements for Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), and Habitat Regulations Assessment (HRA), though there are clear opportunities for aligning reporting to avoid duplication (DEFRA, 2023c)

2.5.4 Phased Implementation Timeline

The rollout of mandatory Biodiversity Net Gain has been strategically phased to ensure manageability and allow for capacity building across the sector. The implementation commenced on 12 February 2024, making BNG a legal requirement for all major developments under the Town and Country Planning Act. This was followed by a significant expansion on 2 April 2024, when BNG was extended to encompass small sites. For the purpose of the policy, small sites are defined as residential developments of 1–9 dwellings (or sites under 0.5 hectares where dwelling numbers are unknown) and commercial developments creating less than 1,000 square metres of floor space or sites smaller than 1 hectare. To facilitate compliance for these smaller projects, a simplified Small Sites Metric (SSM) was introduced. Looking ahead, BNG is anticipated to apply to Nationally Significant Infrastructure Projects (NSIPs) from Autumn 2025, although it is critical to note that this timeline remains provisional and is not yet formalised in legislation (Wentworth, 2024).

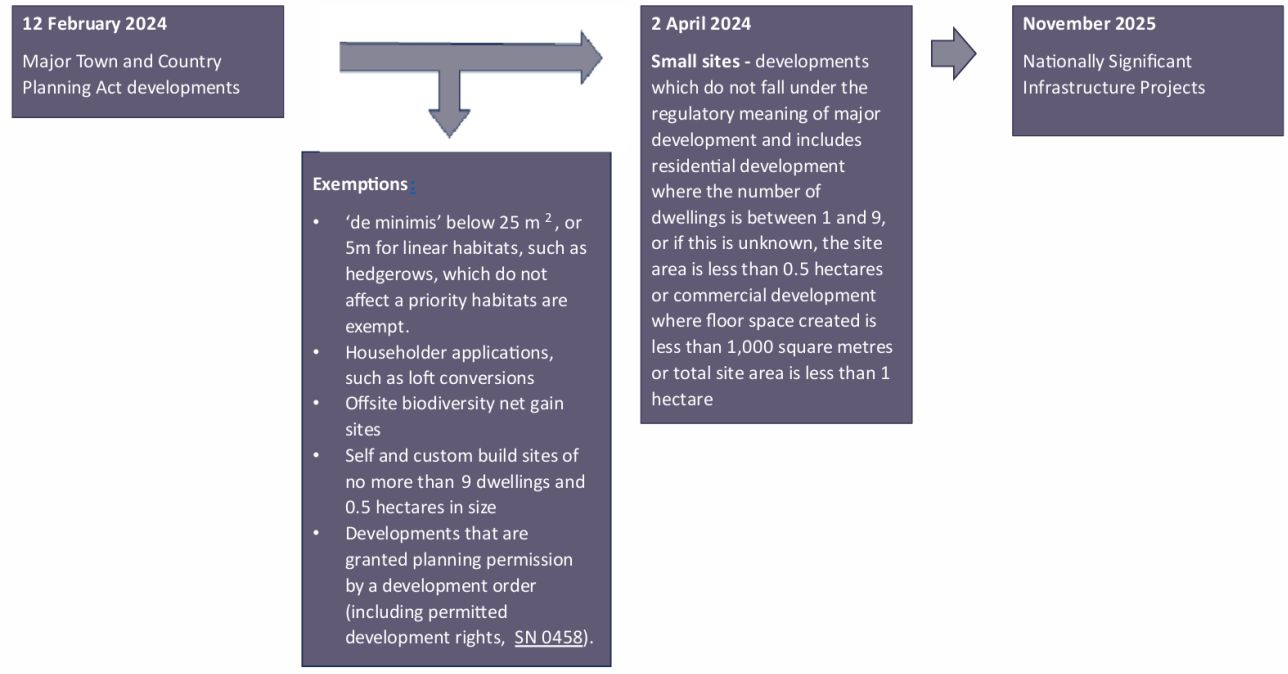


Figure 6. Expected timeline of BNG implementation (Wentworth, 2024)

2.5.6 Strategic Benefits and Synergies with Sustainable Development

Biodiversity Net Gain offers a transformative strategic approach that proactively aligns economic development with ecological restoration, delivering a cascade of co-benefits for nature, society, and the economy. By legally requiring measurable improvements in biodiversity, BNG directly counters the historical trend of habitat fragmentation and loss. It incentivises the creation of more, larger, and better-connected habitats, which enhances overall ecosystem resilience and provides crucial support for species recovery. These enhanced natural capital assets, in turn, strengthen the provision of vital ecosystem services, including climate regulation, water purification, and pollination, thereby contributing to long-term environmental security and social well-being (Natural England, 2024).

The benefits extend significantly into the social sphere. BNG acts as a public health intervention by increasing community access to nature, which is linked to improved mental and physical health outcomes. It also contributes to improved air and water quality and reduces flood risks through the integration of nature-based solutions into development. By mandating these improvements, BNG directly promotes social equity, particularly in urban areas, by ensuring that new housing and infrastructure projects embed accessible green spaces as a standard feature, rather than a luxury add-on (Natural England, 2024)

As a comprehensive policy tool, BNG demonstrates profound alignment with the United Nations 2030 Sustainable Development Agenda. Its most direct contribution is to SDG 15 (Life on Land), as it mandates actions that halt and reverse biodiversity loss through enforceable, measurable gains. Furthermore, through its promotion of ecosystem-based approaches, BNG contributes to SDG 13 (Climate Action) by enhancing carbon sequestration in restored habitats and regulating urban microclimates. The health and well-being benefits facilitated by increased access to green space advance SDG 3 (Good Health and Well-being). Finally, by systematically integrating biodiversity into the fabric of urban and regional planning, BNG is a powerful driver for SDG 11 (Sustainable Cities and Communities), fostering more inclusive, resilient, and environmentally harmonious urban development.

At the policy level, BNG complements broader sustainability strategies and frameworks. Its principles and procedures mirror those found in the Aichi Biodiversity Targets and IUCN policy on biodiversity offsets, reinforcing international commitments to halt biodiversity decline and integrate conservation into development planning. BNG's inclusion in instruments such as planning permissions, licensing systems, and regional development strategies highlights its value as a cross-cutting policy mechanism for sustainable development (BBOP, 2013)

2.5.7. Policy evolution (from NNL to BNG)

The transition from no net loss (NNL) to biodiversity net gain (BNG) in the UK emerged from decades of policy evolution and practical challenges in ecological mitigation. Critical reviews of the Environmental Impact Assessment (EIA) process in the 1990s and early 2000s (Treweek, 1995; Byron et al., 2000) exposed systemic failures in the UK's implementation of the EU's EIA Directive, including poorly enforced mitigation measures, underfunded on-site efforts, and inadequate monitoring. These shortcomings led to continued biodiversity decline, prompting a shift toward restorative action. The UK's Biodiversity Net Gain policy has roots in the 1947 Town and Country Planning System and early EU directives like the Birds Directive (1979) and Habitats Directive (1992), which established baseline protections but failed to reverse biodiversity decline due to weak enforcement of mitigation measures (DEFRA, 2021). The EU 2020 Biodiversity Strategy catalyzed a shift by mandating no net loss and endorsing offsetting mechanisms, which the UK operationalized through Planning Policy Statement 9 (2005), requiring planners to "maintain, enhance, restore or add to biodiversity" and protect habitat networks, and the Natural Environment and Rural Communities (NERC) Act 2006, which imposed a "biodiversity duty" on public authorities. By 2007, Defra recognized the need for market-based solutions, proposing biodiversity offsets to address residual impacts (Defra 2007, 2009). The 2012 National Planning Policy Framework (NPPF) explicitly demanded net gains, supported by pilot offset projects using habitat metrics (DEFRA, 2021; Knight-Lenihan, 2020).

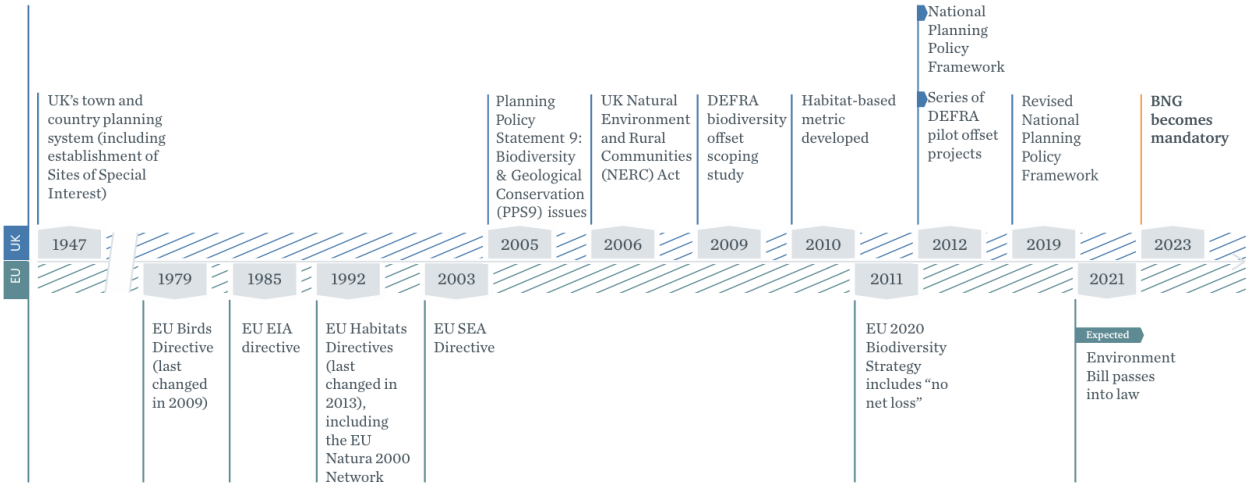


Figure 7. Relevant policy and wider developments influencing BNG in the UK, including influential EU policy (The Nature Conservancy, 2021)

These metrics evolved into the Biodiversity Metric, formalized in the Environment Act 2021, which mandated a 10% net gain for development (DEFRA, 2021). However, critiques persist, early

trials revealed the impossibility of guaranteeing no net loss, while the policy's neoliberal framing risks commodifying nature without ensuring ecological equivalence (Knight-Lenihan, 2020).

2.5.8 The BNG Implementation Process: A Step-by-Step Overview

The BNG process is a legally defined sequence integrated into the UK planning system, designed to ensure compliance and long-term ecological integrity.

Applicability and Core Condition: BNG applies to the vast majority of developments requiring planning permission, including residential, commercial, and infrastructure projects, with specific, limited exemptions (e.g., urgent Crown development). Crucially, it is a pre-commencement condition, meaning construction cannot legally begin until an approved Biodiversity Gain Plan is in place.

The Four-Stage Implementation Process:

Pre-Application Stage: Developers must conduct preliminary assessments to determine BNG applicability and the required percentage gain (a minimum of 10%, though local authorities can set higher targets). Early engagement with the Local Planning Authority (LPA) is encouraged. At this stage, developers prepare Biodiversity Gain Information, outlining the site's baseline value and initial proposals for achieving the net gain.

Planning Application Submission: The Biodiversity Gain Information must be submitted with the planning application. This allows the LPA to assess the development's alignment with BNG objectives at the decision-making stage. Planning permission may be granted conditionally, pending the later approval of a full, detailed Biodiversity Gain Plan.

Pre-Commencement: Biodiversity Gain Plan Approval: Before any construction work begins, developers must submit a comprehensive Biodiversity Gain Plan for formal approval by the LPA. This plan must provide a definitive demonstration of how the minimum 10% net gain will be secured, following a strict hierarchy of options:

- On-site enhancements (the preferred and primary route).
- Off-site compensation (if on-site gains are insufficient).
- Purchasing statutory biodiversity credits (a last resort option). Development is legally prohibited until this plan receives approval.

Post-Approval: Implementation and Monitoring: Once approved, the developer is legally bound to adhere to the conditions of the Biodiversity Gain Plan throughout construction and for the long term. This includes a mandatory 30-year monitoring and reporting commitment (or an agreed alternative period) to ensure that the promised biodiversity improvements are

successfully established and maintained. Compliance is enforced by the LPA through formal regulatory mechanisms (DEFRA, 2021)

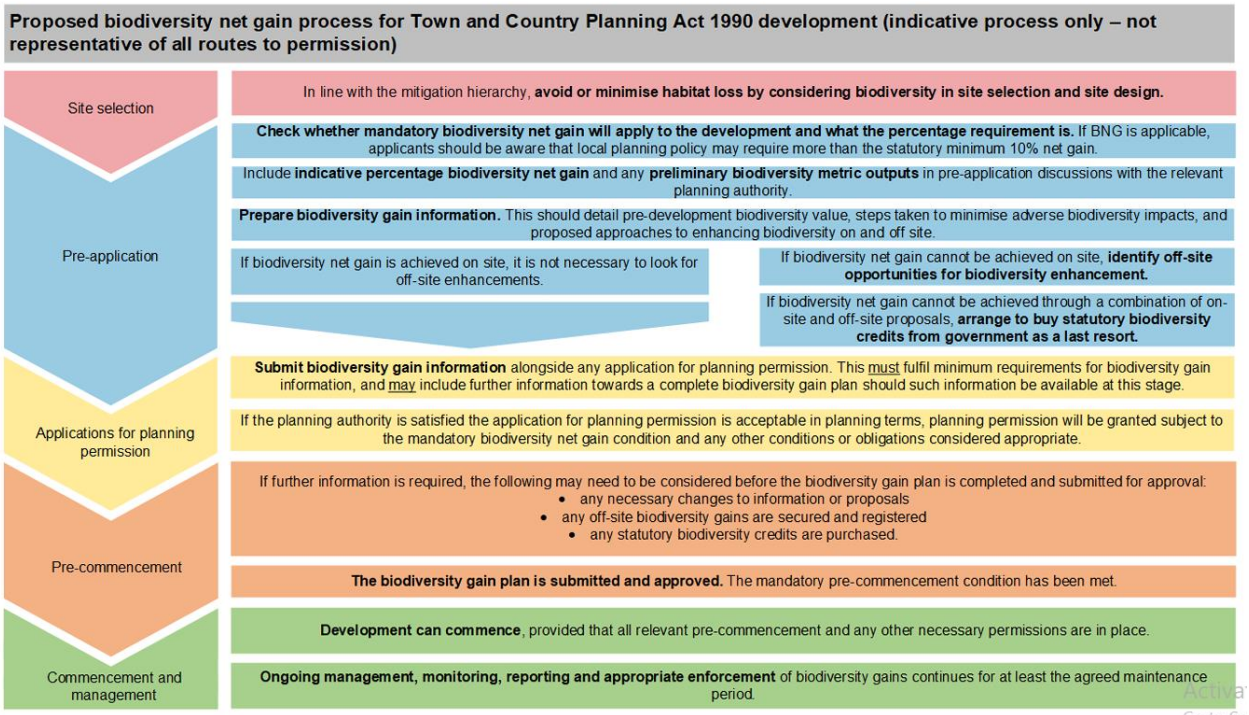


Figure 8. Biodiversity Net Gain process within the Town and Country Planning Act 1990 system (DEFRA, 2022)

2.5.9. Integrating BNG with the Mitigation Hierarchy

Biodiversity Net Gain is designed to work in synergy with, and reinforce, the established mitigation hierarchy. The policy explicitly requires developers to follow a sequential approach that mirrors the hierarchy's principles to achieve the net gain outcome:

Avoid and Minimise: The first and most critical step is to aim to avoid or reduce biodiversity impacts through careful site selection and project design.

On-site Enhancement and Restoration: Subsequently, biodiversity must be enhanced and restored on-site to the fullest extent possible.

Off-site Creation/Enhancement: If on-site measures are insufficient to achieve the 10% net gain, developers must then create or enhance habitats off-site, either on their own land or by purchasing biodiversity units from the market.

Statutory Credits: Only as a genuine last resort, to prevent undue delays to necessary development, can developers purchase statutory biodiversity credits from the government.

This integrated process ensures that the pursuit of "net gain" does not bypass the fundamental responsibility to first avoid and minimise harm, thereby embedding the mitigation hierarchy directly into the BNG framework (DEFRA, 2022).

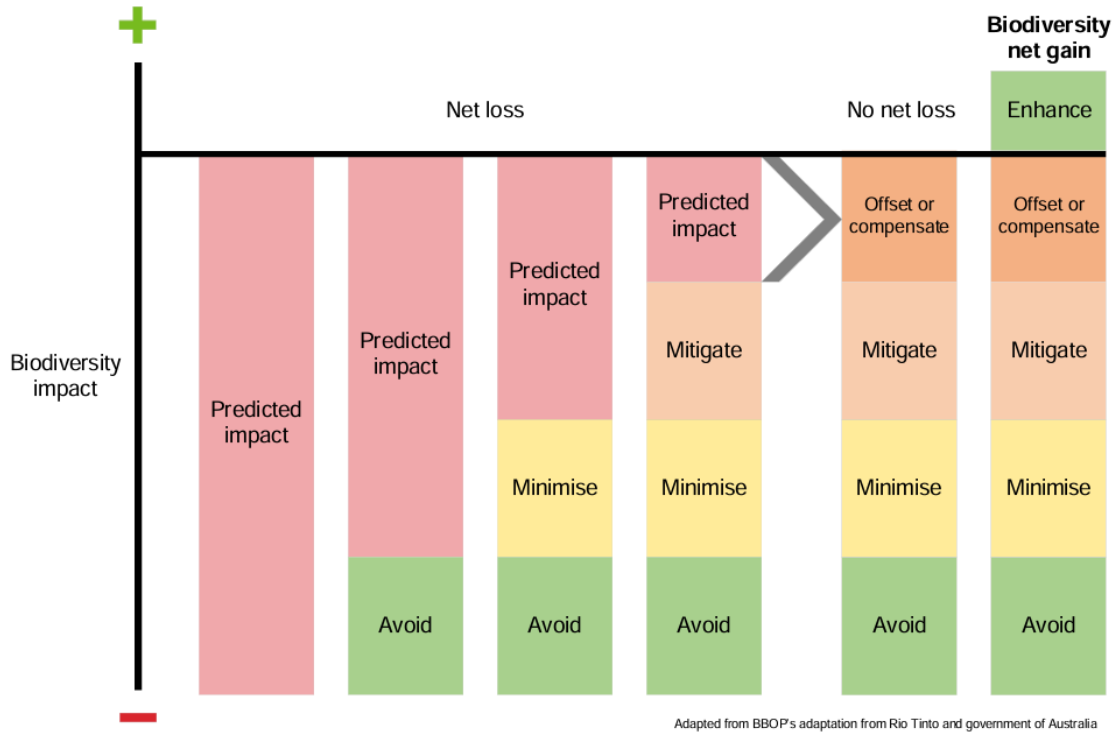


Figure 9. The mitigation hierarchy leading from net loss to biodiversity net gain (DEFRA, 2022)

2.5.10. The Statutory Biodiversity Metric: Measuring Gains and Losses

The core mechanism that makes BNG measurable and standardized is the Statutory Biodiversity Metric (SBM), developed by Defra in collaboration with Natural England. This metric provides the essential tool for quantifying biodiversity losses and gains, translating complex ecological data into standardized "biodiversity units."

The metric's methodology is sophisticated, evaluating habitats based on four key criteria: distinctiveness, condition, size, and strategic significance(Green Finance Institute, 2024). It incorporates a comprehensive classification of over 116 habitat types (using UKHab and EUNIS systems) and applies risk multipliers to account for uncertainties in habitat restoration, such as distance from the development site and potential for establishment failure (Wentworth, 2024).

The SBM is the product of a decade of development, with five iterative versions refined through pilot projects and stakeholder feedback to ensure it is both scientifically robust and practically usable. It is designed to balance multiple principles, ensuring it is: Measurable (using verifiable

proxies), Usable (with a simplified interface), Scientifically robust, Combinable (with other strategies like LNRS), and Impactful (prioritizing high-value habitats) (Green Finance Institute, 2024)

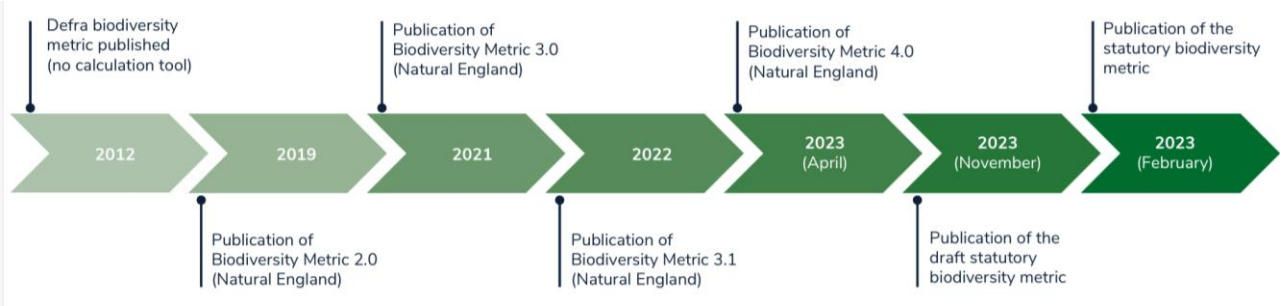


Figure 10. Timeline of Biodiversity Metric Development in England (Green Finance Institute, 2024)

2.6 Critical Challenges in the Early Implementation of BNG

Despite its ambitious design, the initial implementation of BNG since its mandatory inception in 2024 has revealed significant, systemic challenges, creating a substantial gap between policy intent and practical reality.

A primary obstacle is the severely constrained supply of registered off-site habitats. As of 31 July 2024, a mere 9 sites, covering fewer than 300 hectares, were listed in the official Biodiversity Gain Sites Register. This figure is critically short of the government's annual target of 6,700 hectares, indicating profound hesitancy among landowners and conservation providers, likely driven by uncertainties over the 30-year management commitments and questions about the financial viability of such ventures. Concurrently, demand-side engagement has been alarmingly slow. Early data shows that only 0.5% of planning applications submitted in the first five months included BNG provisions. This suggests developers are struggling with the regulatory complexity, seeking exemptions, or are deterred by the substantial administrative, financial, and long-term management burdens imposed by the policy (Green Finance Institute, 2024)

These challenges are exacerbated by a critical capacity gap within Local Planning Authorities (LPAs). As the bodies legally responsible for assessing and enforcing BNG plans, many LPAs lack the necessary in-house ecological expertise and financial resources. This institutional constraint risks inconsistent application of the rules, inadequate scrutiny of Biodiversity Gain Plans, and weak enforcement, potentially undermining the policy's environmental credibility and effectiveness at the local level (Wentworth, 2024)

While local communities stand to gain from the long-term benefits of BNG, such as enhanced green spaces and improved environmental quality, they also face potential risks, including exclusion from decision-making processes surrounding off-site habitat locations or displacement from traditional land uses. These early-stage implementation hurdles highlight the critical need for the structured, multi-stakeholder evaluation that this research undertakes.

2.7 Synthesizing a Robust Assessment Framework for BNG Impact Assessment

This section critically examines established policy evaluation methodologies to construct a robust framework for assessing the impacts of the UK's mandatory Biodiversity Net Gain policy. Given BNG's complex interplay of ecological, economic, and social objectives, a sophisticated approach is required one that moves beyond simplistic metrics to capture its multi-dimensional effects across diverse stakeholder groups. The review begins with the UK government's appraisal and evaluation guidance and complements these with methods proven in adjacent literatures (ecosystem services, nature-based solutions, and green infrastructure). The aim is a framework that is methodologically rigorous, proportionate, and decision-relevant.

2.7.1 UK standards for appraisal and evaluation

Biodiversity and environmental net gain as a policy and mandatory BNG 10% as a requirement, are set in the UK to address the government commitment to improving the environment, benefitting local communities and delivering sustainable development. To effectively assess the impacts of the Biodiversity Net Gain policy, it is essential to Support the evaluation in established policy assessment methodologies.

The Green Book (2022), published by HM Treasury, serves as the UK government’s central guidance for the appraisal and evaluation of policies, programs, and projects. It outlines robust methodologies for assessing costs, benefits, risks, and social value to ensure value for money in public spending, taxation, regulation, and asset management. The guide supports evidence-based decision-making by providing frameworks for monitoring and evaluation at all stages from design to post-implementation. Its principles are applied across central government to assess the effectiveness, efficiency, and legal compliance of government projects and policies.

Evaluation, as defined in the Green Book, is a systematic assessment of an intervention’s design, implementation, and outcomes. Its core purpose is to understand how a policy or project is functioning, what effects it produces, for whom, and why. Evaluation aims to compare real-world results against a “Business As Usual” baseline, to determine the specific added value of the intervention. This process not only supports accountability and transparency in government decision-making but also strengthens the evidence base for improving future interventions and policy design.

Evaluation is typically categorized into two main types:

- Process evaluation assesses whether the intervention is being delivered as intended, within the planned cost and timeline, while identifying what works well or poorly.
- Impact evaluation focuses on what measurable changes occurred and to what extent these changes can be attributed to the intervention itself, including cost-effectiveness analysis and the achievement of SMART objectives.

For regulatory interventions like BNG, the Green Book prescribes a Post-Implementation Review (PIR) to be conducted 3-5 years after enactment, assessing the policy's ongoing relevance, effectiveness, and proportionality, including its costs to business and any unintended consequences.

While a formal PIR for BNG is still several years away, this study is positioned as a critical proactive evaluation that contributes to this future evidence base. It adopts the Green Book's rigorous principles to structure an early assessment of BNG's initial outcomes, providing timely insights for policy refinement.

The Green Book outlines a comprehensive suite of evaluation methods to ensure public policies and planning interventions are rigorously appraised and evidence-based. At the core are two primary tools: Cost-Benefit Analysis (CBA) and Cost-Effectiveness Analysis (CEA). CBA enables decision-makers to quantify all significant costs and benefits in monetary terms, including intangible social and environmental impacts, using a standard Social Time Preference Rate (STPR) of 3.5% to reflect the time value of public resources. Sensitivity analysis is then applied to test the robustness of these estimates to changes in key assumptions (e.g., discount rates, project lifespans). When outcomes cannot be easily monetized, CEA provides an alternative by measuring costs against specific non-monetary outcomes, such as improvements in health or environmental quality.

For complex scenarios involving multiple objectives and stakeholders, such as Biodiversity Net Gain, Multi-Criteria Decision Analysis (MCDA) is recommended. MCDA incorporates stakeholder values and qualitative judgments by scoring and weighting criteria, allowing for balanced decision-making even where monetary valuation is limited. To capture non-market values, methods such as stated preference (e.g., surveys on willingness-to-pay), revealed preference (e.g., observing behavioral data), and hedonic pricing (e.g., examining how environmental features affect property values) are also used.

The Green Book further emphasizes risk analysis, including tools like Monte Carlo simulations, optimism bias corrections, and real options analysis to manage uncertainty and improve the reliability of planning forecasts.

These methods, applied throughout the policy cycle, from initial appraisal to post-implementation review, ensure that interventions are efficient, equitable, and aligned with public value. In the context of BNG, these tools offer a rigorous foundation for evaluating the ecological, economic, and social trade-offs embedded in development planning decisions.

2.8 Implemented evaluation methods for similar BNG and concepts (ESs, NBS or GI)

To determine the best way to assess the impact of the Biodiversity Net Gain 10% requirement on stakeholders, and since it is a novel policy without a prior implementation studies, this research must derive its methodological framework from theoretically adjacent fields. This section conducts a critical review of evaluation methods applied on similar concepts like Ecosystem Services (ESs), Nature-Based Solutions (NBS) and Green Infrastructures (GI) which have been evaluated. These fields share BNG's core characteristic and aim to balance environmental, economic and social goals, their methodological approaches can provide useful insights for evaluation of BNG. By learning from these examples, the suitable methods for measuring BNG's effects can be identified while addressing its unique challenges.

The evolution of evaluation in these fields reveals a critical scholarly consensus: a move away from mono-method assessments towards integrated, pluralistic frameworks.

Haase et al. (2014) conducted a major review of over 200 urban ecosystem service studies. Their findings show a strong preference for certain types of analysis. Researchers most often used biophysical measurements, GIS mapping, and statistical models to map what nature provides. When placing a monetary value on these benefits, studies typically relied on methods like calculating replacement costs or using specific tools like the i-Tree model. For cultural benefits, they often used hedonic pricing (looking at property values) or surveys on willingness-to-pay. Some of these studies then used these monetary values in a formal CBA.

On the other hand, methods that do not use money were used less often. These included simple ecological indicators (for things like carbon storage) and social methods like surveys, interviews, and focus groups. The key problem the review found was that these different methods were rarely combined. There was very little stakeholder participation, few studies looked at multiple ecosystem services together, and analysis of trade-offs was uncommon.

The MAGICA model proposed by Teotónio, Cruz, and Silva (2023) provides a practical example of a hybrid evaluation framework for green infrastructure, explicitly bridging CBA and MCDA. The model's methodology systematically combines a cost-efficiency analysis with a set of stakeholder-weighted criteria processed through MCDA. This structured integration of quantitative economic data with qualitative social values supports transparent and balanced public planning decisions. The MAGICA model thus offers a proven, operational blueprint that

confirms the practical value of hybrid models in environmental planning. It demonstrates concretely how combined methods can effectively accommodate and balance the diverse economic, ecological, and social priorities

The work of Oppio et al. (2024) on urban ecosystem services and Teotónio et al. (2023) on green infrastructure demonstrates the practical efficacy of integrating CBA with MCDA. These models theoretically bridge the gap between the economic rigor required for policy appraisal and the nuanced, value-sensitive judgements needed for social equity. They provide a compelling theoretical foundation for using a combined approach to handle the complex trade-offs.

As Chairat and Gheewala (2024) highlight, their integrated framework for evaluating Nature-based Solutions employs a suite of complementary methods to achieve a comprehensive assessment. The foundation for economic valuation within this framework is CBA, which serves as a comprehensive method for evaluating the economic viability of interventions by systematically comparing all costs and benefits in monetary terms. Its strength lies in its formal inclusion of critical economic considerations: the valuation of externalities (both positive and negative social and environmental impacts), the time value of money (through discounting future costs and benefits), and sensitivity analysis to test the robustness of conclusions against uncertainty. To provide a complete environmental and social context for the CBA, their framework incorporates Life Cycle Assessment (LCA) to quantify long-term environmental impacts and Social Life Cycle Assessment (S-LCA) to evaluate social consequences, all structured within a System of Environmental-Economic Accounting (SEEA EA) to ensure consistency. This rigorous, multi-method foundation is essential for promoting long-term sustainability and ensures that the full value of natural capital enhancements is accurately assessed and accounted for in public and private decision-making.

The review of evaluation methods from environmental fields reveals consistent methodological patterns that inform robust BNG assessment. Previous research demonstrates several critical gaps that this study addresses:

- A persistent over-reliance on technical and monetary methods that marginalizes social dimensions and community values
- Limited application of integrated approaches in mandatory regulatory contexts like national planning policies
- Insufficient attention to long-term implementation feasibility and sustainability beyond initial project phases
- Inadequate systematic stakeholder engagement and transparent trade-off analysis.

These methodological shortcomings are particularly relevant given BNG's early implementation challenges, including low market uptake, capacity constraints in planning authorities, and unclear

community benefit distribution. The policy demands assessment that moves beyond purely monetary impacts to capture its complex multi-stakeholder effects.

The consistent evidence across environmental evaluation literature confirms that effective assessment requires integrating multiple methods. Cost-Benefit Analysis provides essential financial rigor for policy appraisal, while Multi-Criteria Decision Analysis enables incorporation of diverse stakeholder values and non-monetary criteria. The identified gaps in systematic engagement, trade-off analysis, and long-term feasibility directly highlight why single-method approaches are inadequate for BNG evaluation.

This study addresses a critical knowledge gap: the absence of a comprehensive framework for assessing early-stage, multi-stakeholder impacts of mandatory BNG policy. This study provides a structured, evidence-based analysis to identify the distribution of benefits and costs resulting from BNG implementation, while examining how trade-offs between economic, ecological, and social priorities can be managed more equitably. The findings offer timely insights for policymakers and contribute to supporting fairer and more effective implementation of this landmark environmental legislation.

Chapter 3: Methodological Framework (Model Development)

3.Methodological Framework

3.1 Research Design and Analytical Framework

This chapter details the methodology for developing the evaluation model, designed to assess the impacts of Biodiversity Net Gain across three core stakeholder groups of developers, government authorities, and local communities. The framework addresses a critical gap in current evaluation methods by providing a structured approach to capture both quantitative and qualitative dimensions of BNG implementation. The research design adopts a mixed-methods approach that systematically integrates economic valuation with multi-criteria decision analysis to deliver a comprehensive assessment tool for policymakers and practitioners.

The proposed assessment model for this research is COSIMA (COmposite SIgnificance and Multicriteria Assessment), which strategically combines three distinct evaluation methodologies (Barfod & Salling, 2015; Oppio et al., 2024a). Cost-Benefit Analysis (CBA) serves to quantify monetizable impacts, providing economic rigor and facilitating communication with policymakers. Multi-Criteria Decision Analysis (MCDA) complements this by systematically addressing non-monetary criteria such as social well-being, equity, and institutional quality. The framework synthesizes these analyses through a Total Rate of Return (TRR) metric, which integrates financial and strategic values into a single performance indicator, enabling holistic comparison of BNG scenarios (Barfod & Salling, 2015).

The integration of CBA and MCDA, coming together in the TRR, ensures the assessment is neither reductively economic nor subjectively qualitative, but a balanced reflection of BNG's true multi-dimensional value.

3.2. Stakeholder Analysis

Stakeholder analysis is a foundational phase in the assessment of BNG, using the COSIMA model because it ensures that the diverse interests, values and perspectives of all affected parties are considered in decision-making. Also this integration is fundamental to the model's MCDA component, which requires explicit consideration of diverse value systems to ensure the assessment reflects real-world priorities and trade-offs.

BNG initiatives can have significant impacts, for example in terms of social impact, it can change in access to ecosystem services and local well-being, which are often overlooked if only technical or ecological criteria are used. Early and effective integration of stakeholders, helps identify potential risks, address practical challenges, and moves beyond a purely technical or ecological metric to capture the socio-economic and governance dimensions of BNG as well.

This process enhances the legitimacy and practical relevance of the assessment, helps to identify potential risks and conflicts early, and leading to a more robust and equitable assessment.

3.2.1. Methodology for Stakeholder Identification and Selection

The identification of relevant stakeholders for this study was rigorously based on two key reference frameworks that represent the authoritative sources for BNG policy and practice in England.

First, the Biodiversity Net Gain Policy Evaluation Plan 2023–2025 (NECR502) establishes a comprehensive stakeholder typology that classifies actors into core, direct, and indirect groups according to their role and proximity to BNG delivery. Figure 10, shows this stakeholder typology, illustrating how different actors are positioned within the BNG delivery system according to their level of responsibility.

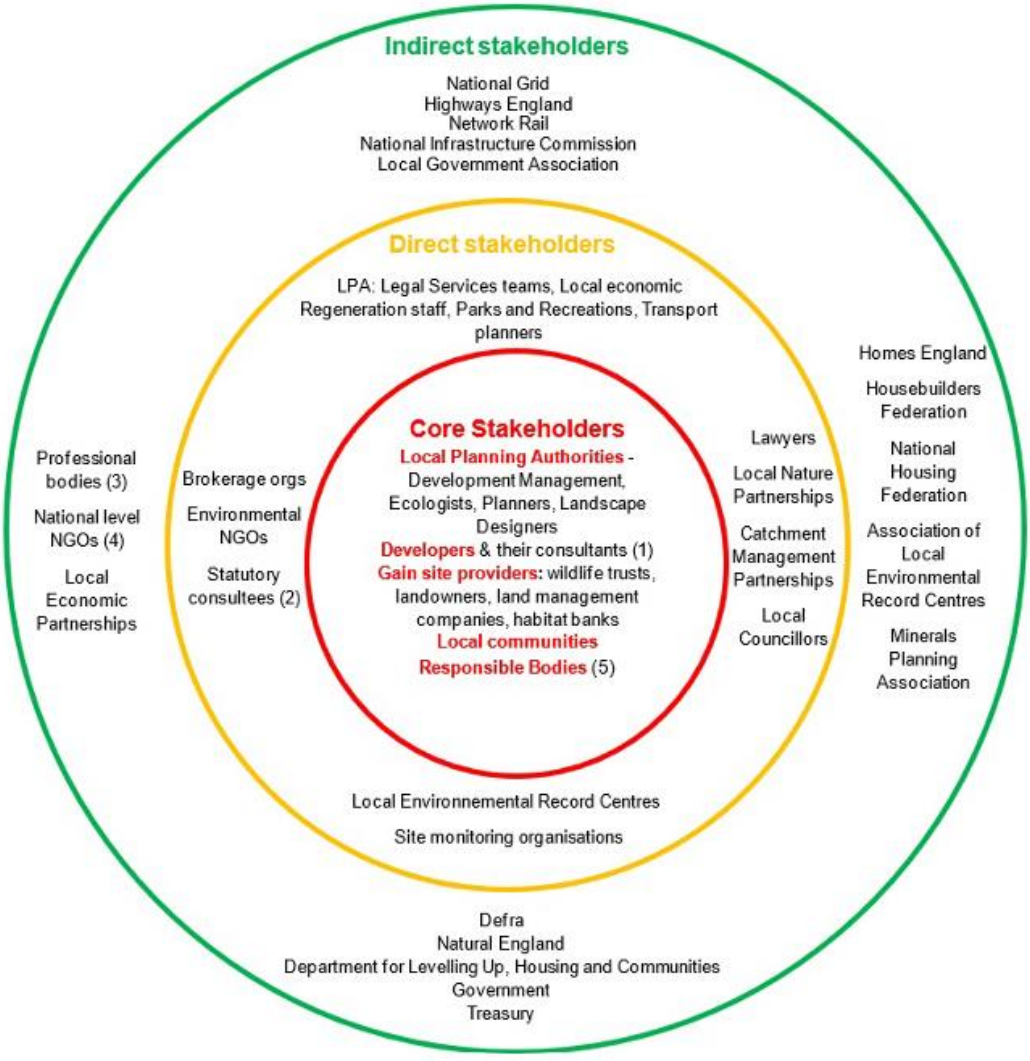


Figure 11. Stakeholders in the BNG intervention system (NECR502, 2023)

- **Core stakeholders** are those with statutory or contractual responsibility for delivering BNG, for example, developers, planning authorities, and statutory nature bodies.
- **Direct stakeholders** are those contributing substantively to BNG implementation through expertise or service provision, such as ecologists, landscape architects, and contractors.
- **Indirect stakeholders** are those influenced by or influencing BNG indirectly, including academia, and wider civil society.

NECR502 highlights that systematic engagement of these groups is essential to evaluate the functioning and effectiveness of the mandatory BNG policy.

The second reference framework is the Biodiversity and Environmental Net Gain (BNG & ENG) Stakeholder Map, which visualizes stakeholder interactions across the project life-cycle, from strategy and baseline assessment to design, implementation, and long-term monitoring. This map illustrates the involvement of multiple actor categories, governmental authorities, designers and technical advisors, developers and asset owners, constructors, utility providers, civil-society organizations, finance and legal actors, and research institutions, across project. The map illustrates the full range of actor categories engaged at different stages of BNG and ENG delivery(DEFRA, 2023c; Natural England, 2024). It provides the broad context from which the key stakeholder groups for this study were selected. The legend identifies key actor categories, including:

- Governmental Authorities (e.g., Local Planning Authorities, Defra)
- Designers, Technical Advisors and Architects
- Developers, Owners and Occupiers
- Constructors
- Civil Society Organisations
- Finance, Legal, and Academia

This map provides a national scale overview of actors involved in the BNG and ENG process. The integration of these two frameworks provided a robust, two-dimensional matrix for identification. The NECR502 typology offered a lens for understanding influence and responsibility, while the Defra map clarified when and how these actors engage. This combined approach ensured a comprehensive scan of the stakeholder landscape, from which the key groups for the COSIMA model were systematically selected.

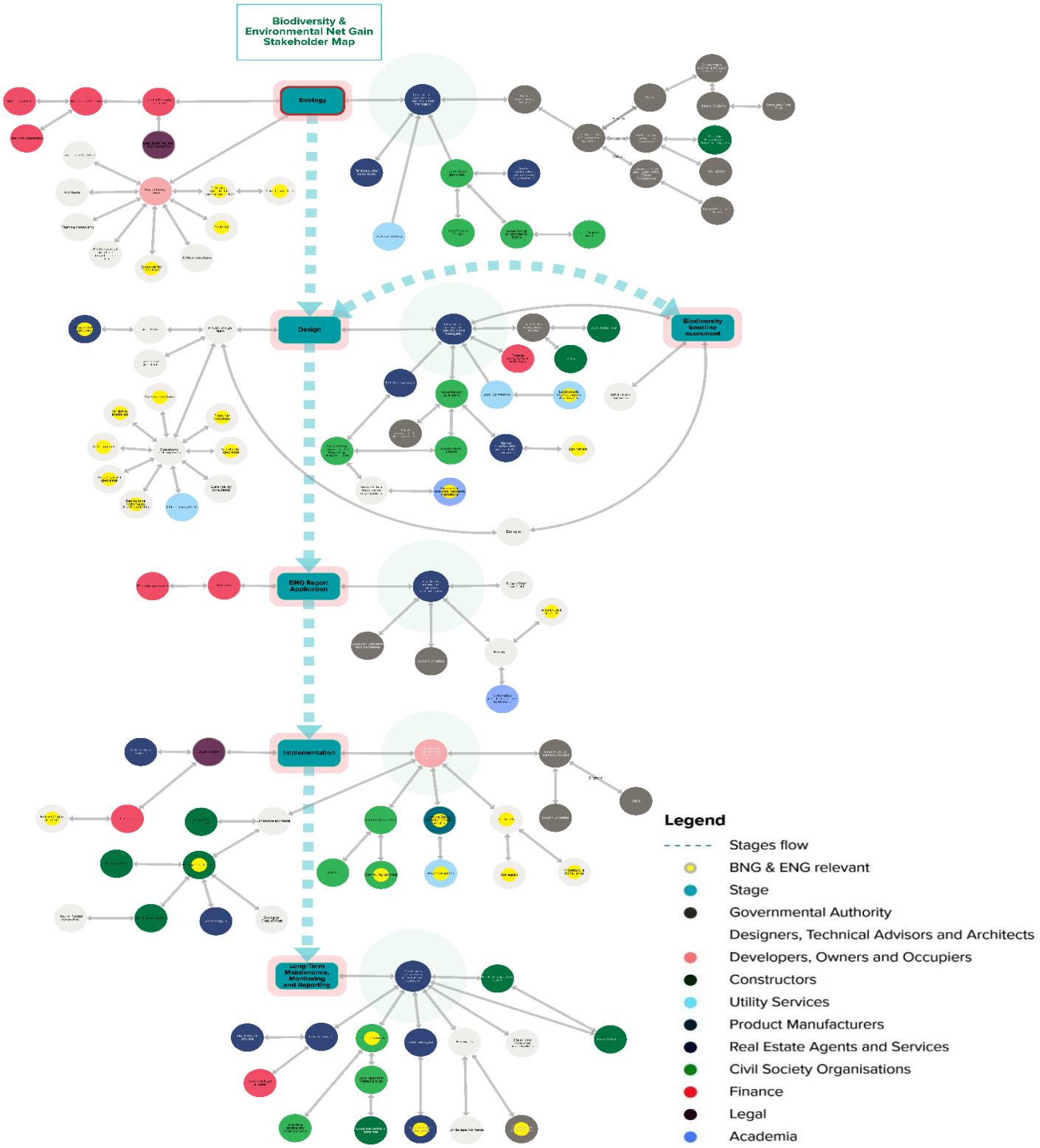


Figure 12. Biodiversity and Environmental Net Gain Stakeholder Map (UK Green Building Council, 2023).

3.3. Indicator Selection Process

The selection of impact indicators for this study was conducted through a dual-stream review process. The first stream was a non-systematic exploratory review of policy documents and grey literature, which established a foundational understanding of the BNG implementation process, facilitated the identification of key impact categories and similar concepts to BNG, and highlighted practical challenges of it in real word. The second stream was a systematic scoping review of academic literature, which provided a transparent and evidence-based foundation of indicators most frequently applied and validated in prior evaluations. This dual-stream synthesis ensured that the final indicator set not only reflects robust academic practice but is also critically aligned with the documented realities and objectives of mandatory BNG, addressing gaps that are often under-represented in scholarly studies.

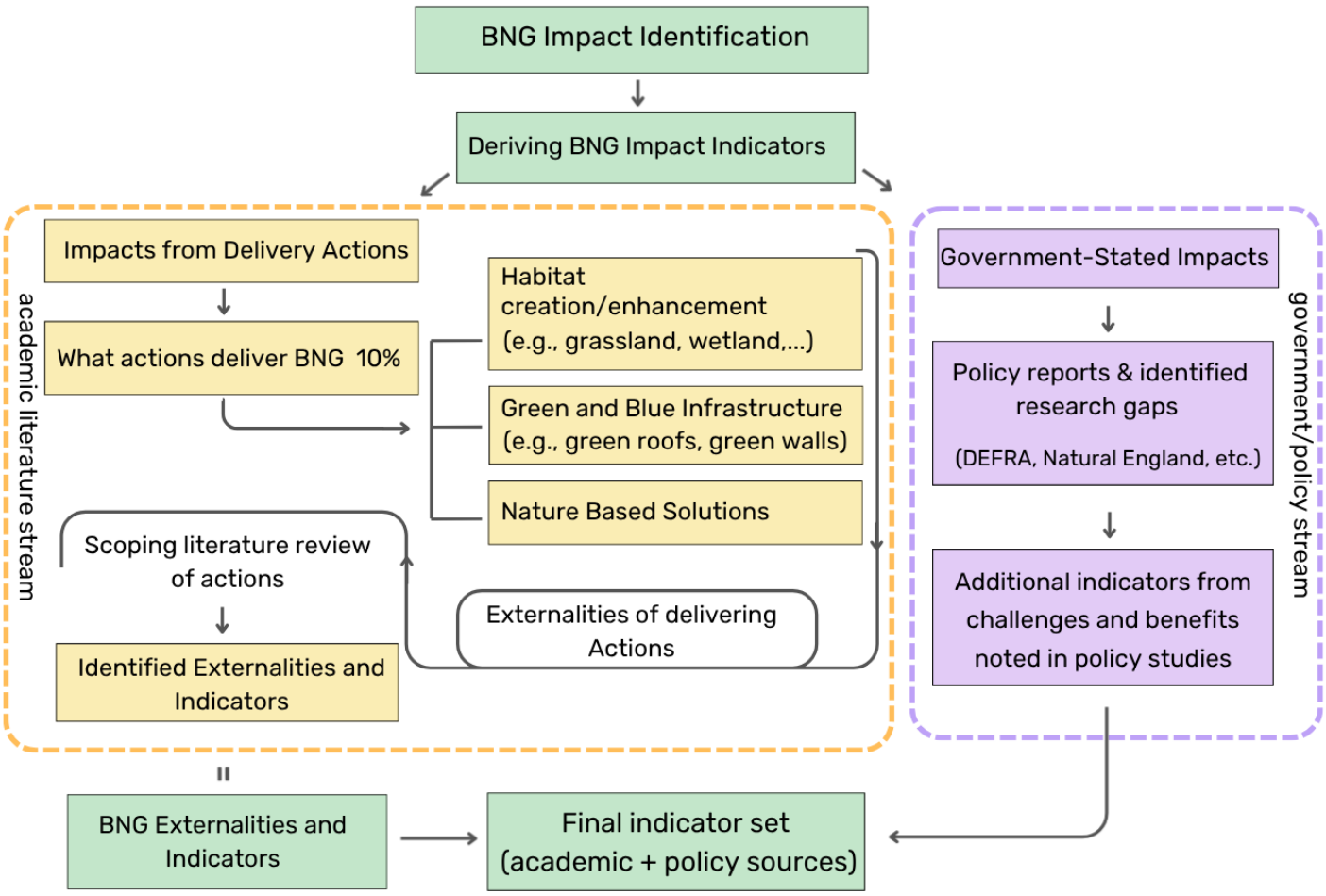


Figure 13. Dual-Stream Process for Identifying and Synthesising BNG Impact Indicators, Author

3.3.1. Non-Systematic Exploratory Review:

This initial review followed non-systematic exploratory review. This method is well-established in policy research. It is particularly useful for mapping complex real-world contexts during the early stages of framework development (Hacking, 2012).

This approach served two key purposes. First, it helped define the problem's scope and identify key concepts. This understanding was essential before designing a more focused, systematic investigation. Second, it allowed us to include vital information from non-peer-reviewed sources. These sources, such as government publications and industry reports, contain essential data on policy implementation and practical challenges (Paez, 2017).

The review provided a comprehensive understanding of the BNG policy. It clarified the procedural workflow, legal mandates, and distinct roles of key actors like developers and Local Planning Authorities(DEFRA, 2022; Natural England, 2024). Critically, it identified a recognized need for a robust BNG impact assessment model. This need is underscored by the UK Green Book. The Green Book mandates Post-Implementation Reviews 3-5 years after a policy's enactment(GOV UK, 2020). This framework aims to meet this future evaluation need.

The review also highlighted several foundational challenges:

- Implementation Gaps: There is a limited supply of registered off-site habitats available for developers to purchase. Simultaneously, developer engagement with the new rules has been slow. This creates a significant barrier to achieving the policy's goals in its early stages (Green Finance Institute, 2024).
- Stakeholder Burdens: The policy introduces substantial new responsibilities. Developers face significant financial and administrative costs for assessments, plan preparation, and long-term management (F. Baker, 2025). For landowners, the 30-year management commitments for habitat banks create a considerable burden, deterring participation (Wentworth, 2024)
- Capacity Constraints: Many Local Planning Authorities (LPAs) lack ecological expertise and financial resources. This shortage risks inconsistent application of the rules and weak enforcement, undermining the policy's effectiveness (Knight-Lenihan, 2020).
- Social Risks: There is a potential for the benefits of BNG to be distributed unequally. Furthermore, local communities are often excluded from decision-making processes about where and how new habitats are created, leading to a lack of local ownership and potential conflict (Taherzadeh & Howley, 2018).
- Knowledge gaps: There are knowledge gaps among developers and planners, and a need for more ecologists and specialist training. Effective BNG delivery requires better

communication and collaboration between planners, ecologists, developers, and local conservation groups

- Systemic Trade-Offs: The policy creates inherent tensions between stakeholder groups. A primary trade-off exists between developer costs and ecological/social gains. There is also a risk of spatial mismatch, where biodiversity gains in one area do not compensate for local losses, creating winners and losers (zu Ermgassen et al., 2019)

Furthermore, the review identified specific on-site and off-site delivery actions that improve biodiversity and form the practical basis for achieving BNG targets. These actions, widely discussed in policy and practice literature (CIEEM, 2021; Natural England, 2024) such as Habitat Creation and Restoration, Green and Blue Infrastructure Integration, Blue Infrastructure Implementation, and Nature-Based Solutions (NBS).

These actions directly guided the next step. They formed the core search topics for the subsequent systematic literature review. The systematic review then sought indicators used to evaluate the multi-dimensional impacts of these specific BNG delivery mechanisms.

3.3.2. Systematic scoping literature review

To identify benefits, and externalities associated with 10% BNG implementation, and impact indicators for measuring the BNG outcomes, this study conducted a scoping review of the academic literature in ScienceDirect, adapted from the Arksey and O'Malley framework using systematic procedures.

By August 2025, no academic studies had been published that specifically assess stakeholder impacts of the statutory 10% BNG requirement in England in ScienceDirect, and most of the available evidence comes from policy guidance and professional practice documents (DEFRA, 2023c; Natural England, 2024). The absence of academic studies on this subject, together with the fact that BNG can be delivered through a range of actions such as green and blue infrastructure, habitat creation, habitat enhancement, and other nature-based solutions, made a scoping review the most suitable method.

A scoping review is particularly valuable when the topic has not yet been extensively reviewed, complex, or broad. It enables researchers to map the extent and nature of available studies, identify gaps, summaries findings, and provide a foundation for further work. Unlike a systematic review, which usually focuses on a narrow question and integrates results across studies, a scoping review allows for broader evidence mapping and supports the development of new frameworks in emerging areas (Hadian et al., 2024).

The objective of the present review is to identify externalities linked to BNG-related delivery actions and extract relevant impact indicators from prior evaluations, providing a transparent

and evidence-based foundation for this study. For transparency, the study reports identification, screening, eligibility, and inclusion using a PRISMA-ScR–style flow diagram.

3.3.3 Literature search strategy

Searches were carried out in ScienceDirect on August 5, 2025 using ten predefined Boolean queries combining terms for BNG and related mechanisms like biodiversity offsetting, ecological compensation, habitat restoration, biodiversity banking, and assessment approaches like cost-benefit analysis, multi-criteria decision analysis. The exact queries are listed in Table below.

keywords	
Search expression	"biodiversity net gain" AND "metric" AND "assessment" "habitat restoration" AND "benefit AND "quantification" "biodiversity net gain" AND "benefit" AND "quantify" "ecological compensation" AND "benefit evaluation" "biodiversity banking" AND "performance indicator" "nature-based solution" AND "benefit" AND "CBA" "nature-based solution" AND "MCDA" OR "multi-criteria decision analysis" "nature-based solution" AND "impact assessment" "biodiversity net gain" AND "benefit" AND "CBA" "BNG" AND "valuation" AND "ecosystem service"

Table 1. Search expressions used in ScienceDirect, Author

As the aim of the literature review was to identify the externalities of actions through which BNG can be implemented, including the benefits they generate, and to extract relevant impact indicators from previous studies, in line with this objective, studies were considered eligible for inclusion if they:

- were published as journal articles in English between 2020 and 2025, examined BNG or comparable mechanisms such as biodiversity offsetting, ecological compensation, biodiversity banking, habitat restoration, or nature-based solutions, and reported measurable indicators related to environmental, social, or economic benefits and impacts.
- Studies were excluded if they did not provide extractable indicators, addressed contexts unrelated to planning or development, or fell outside the defined date, type, or language criteria.

The initial searches returned 3259 records. After applying filters (language, document type, and publication year), 103 articles were retained for download. Following removal of 16 duplicates**,** 87 unique records were screened at title/abstract level. At this stage, 64 records were excluded as irrelevant, mainly because they did not report measurable indicators, were outside the BNG/green infrastructure/nature-based solutions context, or were conceptual reviews without extractable indicators. This left 23 articles that were included in the synthesis. Of these, 18 articles were used for detailed indicator extraction, while the others were used for contextual understanding of BNG-related actions.

Steps	**Procedures**	**Results / Output**
1. Data Gathering	A database search on ScienceDirect using ten predefined Boolean queries combining terms for BNG, related mechanisms (e.g., biodiversity offsetting, habitat restoration), and assessment methods (e.g., CBA, MCDA).	Initial Records: 3,259 records identified.
2. Data Screening	Application of filters for language (English), document type (journal articles), and publication year (2020-2025).	Records after filtering: 103 articles retained for screening.
3. Data Cleaning	Removal of duplicate records.	Unique records: 87 articles.
4. Eligibility Screening	Screening of titles and abstracts based on inclusion criteria: 1. Study examines BNG or comparable mechanisms (e.g., biodiversity offsetting, NBS, GI). 2. Study reports measurable environmental, economic, or social impact indicators. 3. Study provides extractable indicator data.	Records excluded: 64 articles. Articles for full-text review: 23 articles.
5. Full-Text Review & Data Extraction	In-depth analysis of full-text articles. Data was charted using a comprehensive matrix to extract: • Bibliographic information • Methodology (e.g., CBA, MCDA) • Benefit/Impact dimensions • Specific indicators (name, unit, direction)	Final included studies: 18 articles. Output: A dataset of 200+ candidate criteria for the COSIMA framework.
6. Data Synthesis & Analysis	Construction of a comparative matrix to identify the most recurrent indicators. Calculation of indicator frequencies across the literature. Qualitative synthesis of methodological approaches and gaps.	Output: A refined, evidence-based shortlist of the most robust and frequently used indicators, organized by stakeholder group and impact dimension.

Table 2. Literature Screening Process and Results, Author

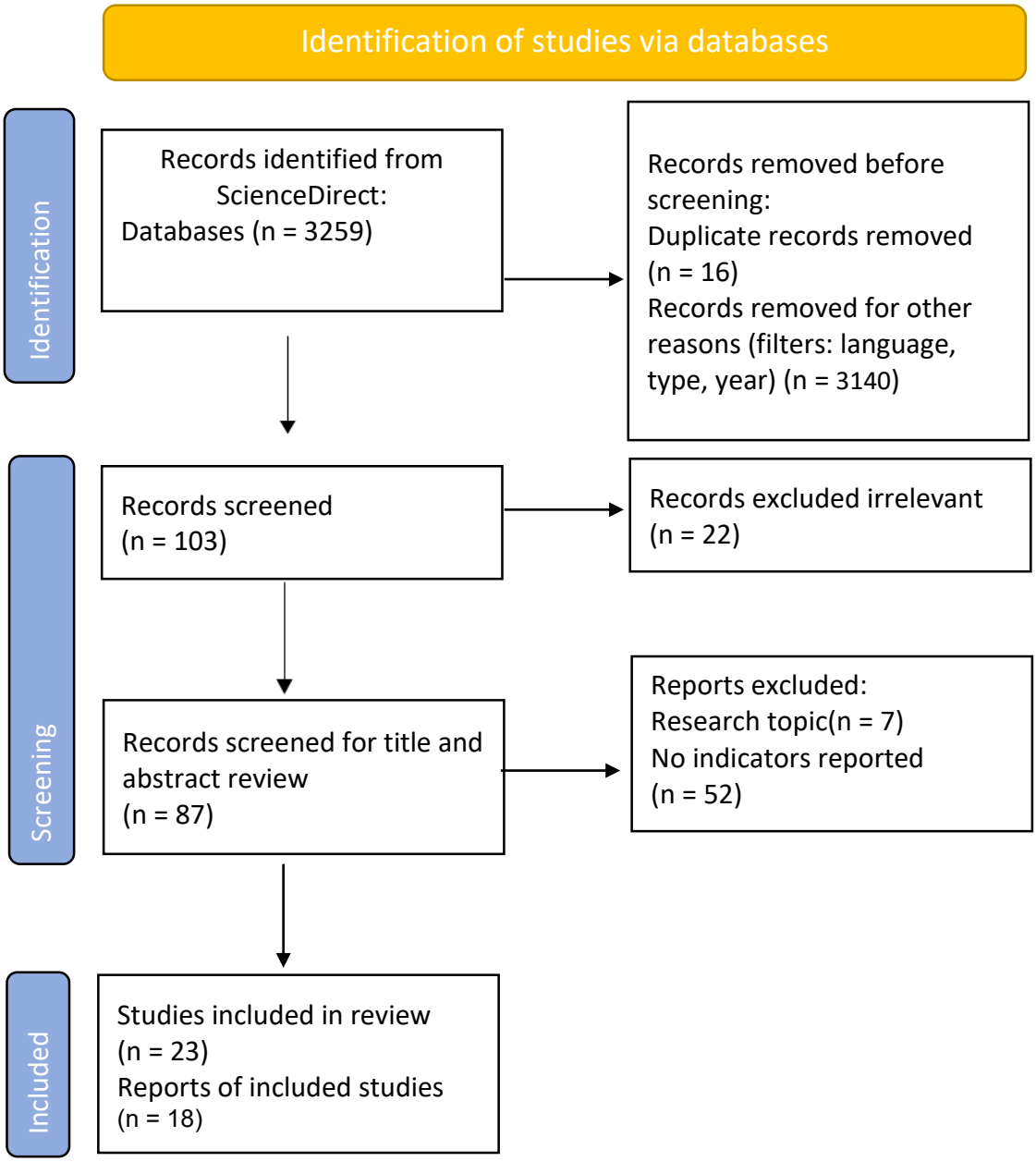


Figure 14. PRISMA 2020 flow diagram for systematic reviews, Author

3.3.4 Data extraction process

The data extraction and synthesis process was conducted in two systematic phases to transform the raw literature into a refined indicator set for the evaluation model.

Phase 1- Comprehensive matrix (data-charting):

A comprehensive data-charting matrix was developed to systematically extract information from each of the 18 included studies. The matrix captured the following categories for every article:

- **Bibliographic information** (Authors, Title, Year, Journal),
- **Case-study context (location/scale),**
- **General methodology** (e.g., CBA, MCDA, modelling, stated-preference),
- **Benefit/impact dimensions** (environmental, economic, social, cultural, governance, technical),
- **Indicators reported** (name, unit/definition, direction of preference),
- **Assessment methodology** (quantitative, qualitative, mixed).

To ensure the quality and practical applicability of the extracted data, two additional quality dimensions were assessed for each study:

First, the robustness of the overall framework or methodological approach (e.g., transparency of assumptions, replicability, comprehensiveness) was noted. Second, the practicality and quality of the indicators themselves were evaluated, including aspects such as ease of measurement, data availability.

Qualitative assessment	Reviewed criteria
Framework robustness	- Transparency of assumptions - Replicability of method - Comprehensiveness of frameworks
Indicator practicality	- Ease of measurement - Data availability - indicators relevancy

Table 3. Quality dimensions used to assess included studies and indicators, Author

All extracted data were systematically organized and managed using a structured Excel database to ensure consistency, traceability, and facilitate subsequent analysis throughout the scoping review process. The data-charting matrix also records the methodological approaches used to generate evidence in the field. This allowed for understanding of how different evaluation methods are applied in practice. Examples in the set include:

- **Integrated Economic-Multicriteria Frameworks:** Applications that combine Cost-Benefit Analysis (CBA) with Multi-Criteria Decision Analysis (MCDA) or the Analytic Hierarchy Process (AHP) to provide a holistic valuation, as demonstrated by the COSIMA and MAGICA models for assessing green infrastructure and ecosystem services (Oppio et al., 2024a; Teotónio et al., 2023).
- **Stated Preference Valuation:** Studies employing Contingent Valuation (CV) and Choice Experiments (CE) to quantify non-market benefits, such as willingness-to-pay (WTP) for improved grassland restoration or the recreational and aesthetic value of green spaces (Cai et al., 2020; Viti et al., 2022).

- **Ecosystem Service Modelling:** The use of specialized biophysical models like InVEST (for carbon, habitat quality, water yield) and SimulSoil to quantify and, in some cases, monetize regulating services such as carbon sequestration, nutrient retention, and flood mitigation (González-García et al., 2025; Oppio et al., 2024b).
- **Standardized Tool-Based Appraisals:** Implementation of dedicated valuation tools, such as the Benefits Estimation Tool (B£ST), to calculate and monetize a suite of environmental and social benefits for specific interventions like green roofs (Koscikova & Krivtsov, 2023).

The evidence base for this synthesis was drawn from a wide range of geographical contexts and spatial scales, ensuring the captured indicators are relevant across diverse implementation settings. The case studies spanned from single building-level interventions (e.g., green roofs and bus shelters) to neighborhood and city-scale urban regeneration projects, and extended to large regional and corridor-level initiatives (e.g., the Araguaia biodiversity corridor in Brazil and grassland restoration in Inner Mongolia).

This methodological mapping directly informed the design of the proposed assessment framework for this study, justifying the need for a hybrid approach that integrates monetary valuation (CBA) with multi-criteria analysis (MCDA) to comprehensively capture the multi-dimensional, multi-stakeholder impacts of BNG.

A condensed summary of the comprehensive extraction matrix is presented in Table 4. This table illustrates the diversity of methods (ranging from CBA and MCDA to stated-preference surveys and tool-based CBAs), the benefit dimensions covered, and the types of indicators reported. The full detailed matrix with all 18 included studies is provided in Appendix A.

Authors (Year)	Case Study / Scope	Methodology used	Benefit Dimensions	Example Indicators*	Assessment
San Jose et al. (2025)	Liverpool, Valladolid, Izmir	MCDA + KPI framework + BACI design	Env, Econ, Social, Tech, Gov	Carbon storage, runoff coefficient, access to green space	Mixed
Viti et al. (2022)	Global review (50 studies)	Stated Preference (CV, CE)	Non-market (people & nature)	WTP for flood prevention, habitat quality, recreation value	Quant
Koscikova & Krivtsov (2023)	Edinburgh (bus shelters)	CBA using B£ST tool	Env, Social	Air quality, carbon sequestration, amenity, health	Quant
Li et al. (2025)	185 urban NbS cases (87 cities)	Systematic review + meta-synthesis (CIOS)	Biodiversity, Human well-being	Species richness, abundance, habitat connectivity	Quant
Oppio et al. (2024)	Turin, Italy (green roof)	Integrated CBA + MCDA (COSIMA DSS)	Env, Econ, Social, Cultural	Carbon, water yield, outdoor activities, accessibility	Mixed
Lucchesi et al. (2024)	Brazil (930,704 ha restoration)	CBA + CEA (discounted cash flow)	Env (global/local), Econ, Social	Carbon sequestration, avoided erosion, jobs, tax revenue	Quant
Cai et al. (2020)	Inner Mongolia (grassland)	Choice Experiment + Mixed Logit	Env, Econ, Social, Policy	Vegetation cover, groundwater, rare animals, WTP	Quant

Table 4. Summary of methodological approaches and indicator coverage in included studies, Author. Full matrix with all studies, methods, and indicators in Appendix A.

Phase 2- Comparative Indicator matrix and Frequency Analysis

Following the comprehensive data extraction, the next phase involved a rigorous synthesis to transform the longlist of over 200 indicators into a coherent set for the assessment framework. This was achieved through the construction of a comparative indicator matrix and a systematic process of conceptual consolidation.

To mitigate redundancy and ensure terminological consistency, duplicate and semantically overlapping indicators were merged under unified, standardized labels. This process was essential to avoid double-counting and to identify the core conceptual measures that are most valued across the literature. For instance, indicators such as "Air purification," "Air quality parameters (NOx, VOC, PM)," and "Annual mean levels of PM2.5" were consolidated into the unified indicator "Air Quality Regulation and Pollutant Removal." A full mapping of the unified

indicators is documented in Appendix A. This consolidation enhances the analytical clarity of the dataset, allowing for a more accurate assessment of an indicator's prevalence and importance.

The consolidated indicators were organized into a comparative matrix where each row represents a study and each column a unified indicator. A checkmark (✓) denotes the reporting of a given indicator within a study. This structure provides a transparent, visual overview of the evidence base, making it easy to identify which indicators are most commonly applied and where gaps in the literature may exist. In addition, metadata were recorded for each indicator, including were recorded:

- **Scalability** (building, neighborhood, city, regional, global);
- **Aggregation method** (e.g. additive, index, per capita);
- **Validation status** (applied in practice vs. theoretical proposals);

Table 5 provides an illustrative excerpt of this matrix. It is important to note that a single checkmark in the matrix often represents the consolidation of several related metrics from the original study. For example, a checkmark for "Flood & Erosion Risk Reduction" may indicate that the original study reported on one or more of the following: "Avoided flood damage cost," "Flood mitigation," "Erosion regulation capacity," or "Sediment Retention."

The finalized matrix enabled a quantitative frequency analysis, counting how many studies utilized each unified indicator. This analysis served two key purposes:

- Identifying Robust Indicators: The most frequently occurring indicators were identified as having strong support across diverse methodological approaches and case studies, providing a robust, evidence-based foundation for the final framework.
- Highlighting Research Gaps: The matrix visually highlights under-represented dimensions, such as specific governance metrics or long-term socio-economic indicators, pointing to areas where future research and indicator development are needed.

Authors (Year)	Case Study	Carbon Sequestration	Runoff Reduction	Air Quality	Biodiversity	Recreation	Property Value	Jobs Created	Governance (participation)	Governance (fairness/trust)	Scalability	Validation
San Jose et al. (2025)	Liverpool, Valladolid, Izmir	✓	✓	✓	✓	✓	–	✓	✓	✓	City	Applied
Viti et al. (2022)	Global review	✓	–	✓	✓	✓	✓	–	–	–	Global	Review
Koscikova & Krivtsov (2023)	Edinburgh (bus shelters)	✓	✓	✓	✓	–	✓	–	–	–	Local	Applied
Li et al. (2025)	185 urban NbS cases	✓	✓	✓	✓	–	–	–	–	–	Multi-city	Review
Oppio et al. (2024)	Turin, Italy (green roof)	✓	✓	✓	✓	✓	✓	✓	✓	–	Building	Applied
Lucchesi et al. (2024)	Brazil Corridor (930,704 ha)	✓	✓	–	✓	–	✓	✓	–	–	Regional	Applied
Cai et al. (2020)	Inner Mongolia (grassland)	✓	–	–	✓	✓	–	–	–	–	Regional	Applied
González-García et al. (2025)	Alpine NbS actions	✓	✓	✓	✓	–	–	–	–	–	Regional	Applied

Table 5. Excerpt from the Comparative Indicator Matrix after Conceptual Consolidation, Author (Note: A ✓ indicates that one or more related metrics for the unified indicator were reported in the study.) The complete matrix is provided in Appendix A.

3.3.5. Synthesis of Indicator Patterns and Gaps

The comparative review of more than 200 indicators shows that existing BNG-related assessment frameworks tend to emphasize on a limited set of dimensions. Out of the 200+ indicators identified, the largest group relates to Biodiversity and Habitat, reflecting the strong focus on habitat quality, species diversity, and ecological connectivity that underpin the BNG policy framework. Climate and Air indicators are also well-represented, frequently measuring carbon sequestration, air purification, and temperature regulation. Economic and Financial metrics form another major group, where the costs of implementation, installation, and maintenance are the most common concerns, alongside job creation and property values.

In contrast, several critical dimensions are measured less often. Social and Cultural outcomes, like community well-being, recreation, aesthetic value, and social cohesion, are identified but not consistently assessed. Similarly, Governance and Participation indicators, which track stakeholder engagement, equity, and trust, are the least common. This suggests that the human and social processes essential for long-term project success are not being systematically monitored.

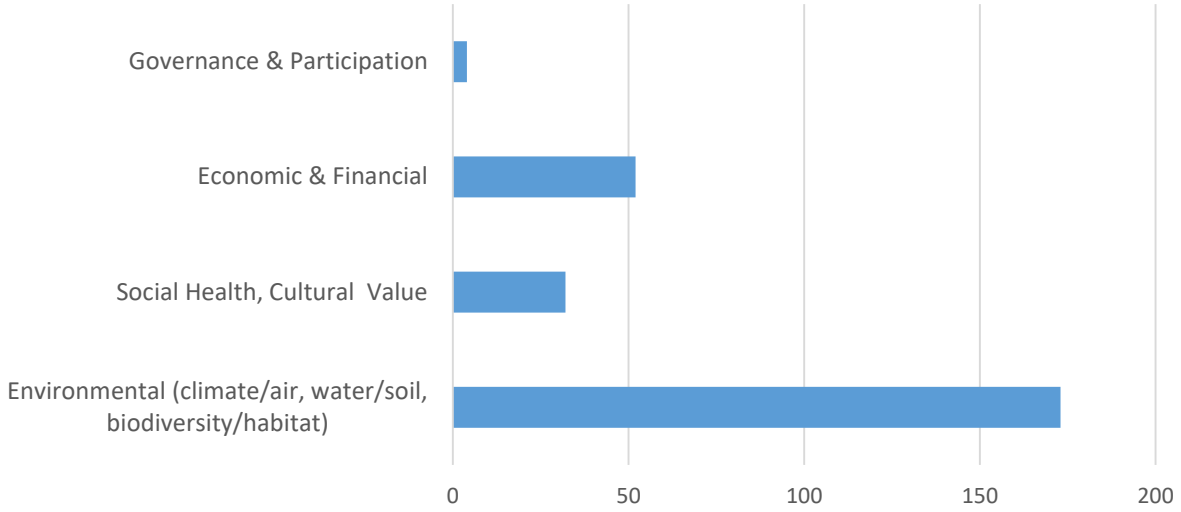


Figure 15: Frequency of BNG Assessment Indicators by Thematic Dimension, Author

Despite the wide range of potential metrics, a core set of indicators appears repeatedly across different studies, forming a robust evidence base for BNG. The most frequent indicators are:

- Climate Regulation and Air Quality: This includes overarching climate regulation, specific metrics for carbon sequestration, CO_2 and GHG mitigation, and air purification.
- Social and Health Outcomes: Frequently measured social benefits are improvements in health and well-being, aesthetic appreciation, social inclusion and cohesion, and worry reduction.
- Economic and Financial Metrics: Cost-related indicators are dominant, particularly maintenance cost, total implementation cost, and construction and installation costs. On the benefits side, increase in property values and property value growth are common.
- Water and Risk Mitigation: Key infrastructure benefits include stormwater drainage benefit and disaster risk reduction.

- Biodiversity and Ecological Value: Core ecological measures are captured by species diversity indices, while the broader ecosystem services value is often used to aggregate benefits.

This frequency-based analysis provided a robust, evidence-informed foundation for selecting the final indicator set for the COSIMA framework, while simultaneously highlighting critical areas where additional indicator development is needed to comprehensively capture BNG's multi-dimensional impact.

3.3.6 Initial Classification of Candidate Indicators by Stakeholder Domain

Following the comprehensive dual-stream review, which encompassed both the systematic scoping of academic literature and the exploratory analysis of policy documents, a longlist of indicators was identified. To align this extensive set with the COSIMA model's design, an initial classification was performed, mapping the most common indicator to its primary relevant stakeholder group: Developers, Government, or Local Communities. This preliminary organization formed the basis for subsequent expert validation and refinement phase.

Stakeholders	Candidate Indicators	Dimension
Developers	Implementation costs	Economic
	Maintenance costs	Economic
	Credit price	Economic
	Registration fees	Economic
	Increased bureaucratic time or planning delays	Economic
	Receipt of government incentives	Economic / Governance
	BNG compliance	Environmental
	Policy/plan congruence	Governance
Government	Flood risk reduction	Environmental
	Monitoring capacity	Governance
	Institutional trust	Social / Governance
	Carbon sequestration	Economic / Environmental
	Monetary values of ecosystem services	Economic / Environmental
	Job creation	Social / Governance
	Stakeholder satisfaction	Social / Governance
Local Communities	Access to green space	Cultural / Social
	Aesthetic quality	Cultural / Social
	Recreation value	Cultural / Social
	Air quality benefits	Health, Well-being
	Energy bill savings	Economic
	Property value uplift	Economic
	Inclusion in decision-making processes	Social / Governance
	Perceived fairness of offset locations	Social
	Well-being improvements	Social / Health

Table 6. Preliminary Classification of High-Frequency Candidate Indicators by Stakeholder Domain, Author

3.4. Expert Validation and Indicator Weighting Procedure

To ensure that the indicator set is both robust and practically applicable, a structured expert validation and weighting procedure was implemented. This process had a dual purpose:

- to verify the face and content validity of all indicators (both CBA and MCDA), and
- to derive a set of relative weights for the MCDA criteria that reflect informed professional judgement.

3.4.1 Expert Panel Composition

A purposive, heterogeneous panel of four experts was assembled to ensure that the framework is credible across the full domain of BNG implementation. The panel included:

Academic researchers, providing theoretical rigour, familiarity with valuation and assessment methods, and experience in multi-criteria frameworks.

Industry practitioners, contributing knowledge of practical feasibility, delivery constraints and the economics of development projects.

Policy and public-sector experts, ensuring alignment with BNG policy objectives, regulatory requirements and local government implementation realities.

This diversity was intended to produce an indicator set and weighting structure that integrates research, practice and policy perspectives, rather than reflecting a single disciplinary or professional viewpoint.

3.4.2. Validation Survey Instrument and Procedure

A structured expert questionnaire was developed to systematically collect and quantify expert judgements. The questionnaire was administered via a web-based tool and organised into sequential stages:

Stage 1: Indicator validation for all indicators (CBA and MCDA)

Experts were presented with the complete list of candidate indicators, grouped by stakeholder perspective (developers, government, local communities). For each indicator, experts were asked to:

- assess its relevance, clarity and feasibility for use in BNG evaluation,
- rate its importance on an ordinal Likert scale (e.g. from “Low” to “Very High” importance),
- provide qualitative comments, suggestions where necessary.
- indicate whether the indicator should be included or excluded, giving a brief justification for any proposed exclusion, and, where appropriate, propose additional indicators they considered missing from the initial list.

This stage served to test the conceptual soundness and practical measurability of the indicators and to refine the longlist constructed from the literature review.

Stage 2: Weight elicitation for MCDA criteria

Following the validation stage, the experts were directed to the finalised subset of indicators designated as MCDA criteria. The number of MCDA criteria presented at this stage was deliberately limited in order to keep the weighting exercise cognitively manageable. A more focused subset of key indicators helps experts make clearer trade-offs. For this refined set of MCDA criteria, each expert was asked to distribute 100 points among the indicators, reflecting their perceived relative importance, with higher point allocations indicating greater strategic weight in the overall assessment of BNG performance. This direct point-allocation method offers a transparent and cognitively manageable way of deriving weights, and allows experts to express both within-domain and cross-domain priorities. The resulting data form the empirical basis for the subsequent analysis. In Chapter 4, these inputs are converted into numerical scores, summarised (e.g. by means and standard deviations), and normalised weights, and are then used to distinguish between core, context-dependent and optional indicators within the COSIMA framework. For completeness, the full text of the BNG Indicators Expert Questionnaire is reported in Appendix B.

Chapter 4: Framework Structuring and Validation (Conceptual Application)

4.Framework Structuring and Validation

This chapter presents the results of the validation questionnaire and conceptual development of the COSIMA assessment model with its validated indicators. It translates the methodological steps outlined in Chapter 3 into a validated, operational framework. It reports the results of the stakeholder analysis, the final output of the dual-stream literature review, which is a classified set of indicators, and the outcomes of the expert validation and weighting procedure, which refined the indicator set in relative stakeholder domains. The chapter concludes with the presentation of the final structured COSIMA framework, including the validated indicators and its integrated CBA, MCDA and TRR frameworks. Together, these steps ensure that the framework is evidence-based, grounded in expert judgement, and ready for empirical application.

4.1. Stakeholder Identification and Selection

The comprehensive stakeholder analysis, guided by the NECR502 typology and the Defra BNG & ENG Stakeholder Map, provided a foundation for defining the model's scope. Comprehensive mapping of the stakeholder confirmed that the three selected groups, Developers, Government (local authorities), and Local Communities**,** capture the fundamental perspectives necessary for a holistic evaluation of BNG trade-offs.

The final grouping is identified below, demonstrating how the broad stakeholder landscape was distilled into the core model participants:

1. Developers (Core Stakeholders): This group includes the actors such as site owners, project developers, and their consultants responsible for planning, financing, and carrying out development projects. Their perspective is essential for capturing the economic and technical feasibility of BNG, including direct costs, financial implications, and the practical challenges of habitat creation and management. They represent the principle of implementation.

2. Government (Core Stakeholders): This group comprises the regulatory and oversight bodies, mainly Local Planning Authorities (LPAs), with legal duties for spatial planning, development control and environmental protection. Their input is critical for understanding the regulatory, administrative, and long-term governance aspects of BNG, including compliance monitoring, policy alignment, and the safeguarding of the public interest.

3. Local Communities (Core-Indirect Stakeholders): This group consists of residents and local community who are the ultimate users and beneficiaries of BNG outcomes. While they are directly affected by the social and environmental results, they typically have little formal power in its delivery. Their perspective is necessary for capturing social value, distributional fairness,

and perceived quality of life, ensuring the model evaluates not just procedural success but also the actual experience on the ground.

This structured prioritization ensures that the subsequent stages of indicator selection and weighting are grounded in the values and interests of these decisive groups.

4.2. Results of the Literature Review and Final Indicator Set

The dual-stream literature review, comprising a systematic scoping review and an exploratory policy analysis, initially generated a longlist of potential indicators. A rigorous screening process, based on relevance, measurability, and alignment with BNG objectives, refined this list to 26 candidate indicators**.**

These candidate indicators were then classified according to the primary domain of the three key stakeholder groups to ensure a balanced and representative structure for the subsequent MCDA. This classification formed the basis for the expert validation questionnaire, ensuring that the indicators presented were pre-vetted for relevance to each stakeholder group's core concerns.

4.2.1. Final extracted indicator set for assessment

The final set of indicators for the comprehensive assessment of BNG was derived from the systematic scoping review and comparative analysis, and subsequently refined through the expert validation process described in Chapter 3. The selection was guided by the need to balance conceptual completeness with practical measurability, resulting in a framework that captures the multi-dimensional value of BNG interventions while remaining usable in ex-ante decision-support.

A key refinement involved resolving double-counting and conceptual overlap between indicators. For instance, separate metrics for flood risk and stormwater management were merged, as they reflect the same underlying regulating service. Similarly, to avoid conflating drivers with their outcomes, broad well-being indicators were removed in favor of more specific, measurable determinants (e.g. access to green space, opportunities for recreation). This ensures that each indicator represents a distinct dimension of value within the overall assessment.

The framework is explicitly designed for predictive assessment. This required confirming that every indicator can be populated with ex-ante information, such as benefit transfers from the literature, parametric cost estimates or expert-scored criteria, rather than relying solely on ex-post monitoring data. In operational terms, the identification of data sources and valuation functions was carried out with specific reference to the Italian planning context (e.g. national statistics, municipal plans, and Italian/EU valuation studies), ensuring that the indicators can be

implemented in real decision-making settings. For the CBA indicators in particular, each item was associated with a clearly specified valuation approach and at least one feasible data source in the Italian context, so that economic appraisal remains both credible and operational in practice, while still being conceptually transferable to other jurisdictions.

In parallel, the framework was formulated so that it can be adapted beyond the English statutory context, including settings where no legally binding BNG threshold is in place. For example, the UK's mandatory +10% BNG compliance metric was reframed as "BNG uplift ambition", which can express voluntary commitments to ecological enhancement in other jurisdictions (e.g. an Italian municipality). Conversely, an indicator for "planning delay risk" was initially considered, given the additional procedural steps introduced by BNG-like policies, but was ultimately excluded. Although conceptually relevant as a policy-related risk, it proved difficult to estimate reliably with available information, underscoring the commitment to include only indicators that are practically measurable within the COSIMA framework.

A central finding of the literature and stakeholder analysis was that the perceived success of BNG depends on addressing the distinct priorities of different actor groups. To keep the framework policy-relevant and useful for decision-makers, the final indicators are therefore organised according to three primary stakeholder perspectives:

Developer perspective: This category encompasses indicators directly related to project feasibility and private returns, including upfront capital expenditures, long-term maintenance liabilities, exposure to regulatory costs (e.g. credits or off-site units) and the availability of fiscal or reputational benefits. These metrics are essential for evaluating the private costs, risks and potential advantages associated with BNG delivery.

Government perspective: Indicators in this group assess the alignment of BNG projects with public policy objectives and regulatory duties. They include contributions to strategic goals such as climate resilience, biodiversity targets, job creation and alignment with wider policy frameworks (e.g. Green Infrastructure, climate strategies, SDGs), as well as indicators related to administrative capacity and long-term governance. This perspective evaluates the public value generated by BNG and its cost-effectiveness from a governmental standpoint.

Local community perspective: This category captures the localised social, cultural and health-related co-benefits of BNG, such as equitable access to green space, perceived environmental quality, opportunities for recreation and social interaction, and impacts on well-being and social equity. These indicators are crucial for understanding how BNG interventions affect everyday quality of life for residents and how benefits and burdens are distributed across different groups.

Together, these three perspectives structure the indicator set so that COSIMA can support integrated appraisal of BNG projects across ecological, economic, social and governance dimensions, while remaining anchored in stakeholder-relevant outcomes.

4.2.1.1. Overview of the Final Indicator Set for Validation

Table 7, presents the comprehensive set of 26 candidate indicators derived from the literature. This set served as the core proposal submitted to experts for validation and weighting. The table details each indicator's proposed analytical treatment (CBA or MCDA), measurement unit, and a justification for its initial selection, providing a transparent basis for expert evaluation.

For each indicator, the following information is detailed:

Stakeholder Group and ID: The primary beneficiary and a unique identifier for easy reference.

Indicator Name: A concise description of what is being measured.

Type (CBA/MCDA): The analytical method to which the indicator is assigned.

Data Type: The fundamental nature of the data (e.g., Monetary, Quantitative, Qualitative), which dictates how it is processed within the CBA or MCDA model.

Unit: The specific unit of measurement, providing clarity and ensuring consistency in data collection and analysis.

Main Data Source: The origin of the data, indicating the practical feasibility of populating the indicator.

Rationale for Inclusion and Method Assignment: A critical justification explaining why the indicator was selected and why it is suited for either CBA or MCDA, linking back

Stakeholder Group	ID	Indicator Name	Type (CBA/MCDA)	Data Type	Unit	Main Data Source	Rationale for Inclusion and Method Assignment
Developers	B1	Cost of BNG Delivery (On-site) / GI Delivery	CBA – Cost	Monetary	€/m², €/tree, €/unit	DEI – Construction Cost Manuals; Regional Price Lists; City of Turin – Public Works Department	A primary driver of developer feasibility. Highly monetisable through standard construction cost databases.
	B2	Cost of BNG Delivery (Off-site)	CBA – Cost	Monetary	€/ha or €/m²	ISPRA – Land Consumption & Restoration Reports; LIFE Projects Database	Captures the financial alternative of off-site compensation, a key element in BNG policy. Costs are benchmarked from similar restoration projects.
	B3	Statutory Biodiversity Credit Price (proxy for IT)	CBA – Cost	Monetary	€/tCO_2e or €/ha habitat creation	EU ETS / Voluntary Carbon Markets; DEI – Green Works / Ecological Engineering	Acts as a proxy for a compliance cost in a nascent market. Monetisable via credit prices from analogous environmental markets (e.g., carbon) or engineering cost estimates.
	B4	Biodiversity Gain Site Registration Fee (proxy for IT)	CBA – Cost	Monetary	€/application	Regional / Municipal administrative fee lists (SUAP, VIA, VINCA)	Represents a direct, monetisable transaction cost associated with the regulatory process of registering a BNG site.
	B5	Maintenance Cost (30-year)	CBA – Cost	Monetary	€/m²/year or €/tree/year (NPV 30 yrs)	DEI – Maintenance Cost Manual; City of Turin – Green Plan / Contracts	Critical for assessing the long-term financial commitment. Can be monetised as a Net Present Value (NPV) stream, reflecting the total cost of ownership.
	B6	Government Incentives / Subsidies	CBA – Benefit	Monetary	€ per project / grant	MASE – Funding and Incentive Programs; PNRR – Mission 2; LIFE / PSR	A direct financial benefit that improves project viability. Easily monetised based on grant values or subsidy amounts.
	B8	BNG Uplift Ambition	MCDA – Criterion	Quantitative	% Net Gain/ n° native plant and species	ISPRA – National Natural Capital Reports; ARPA Piemonte – Ecological Network	The core ecological outcome. Assigned to MCDA as a quantitative criterion to be weighted against other objectives, as its "value" is not solely monetary but also ethical and regulatory.

Stakeholder Group	ID	Indicator Name	Type (CBA/MCDA)	Data Type	Unit	Main Data Source	Rationale for Inclusion and Method Assignment
Local Authorities	C1	Urban Flood Risk Mitigation	CBA – Benefit	Monetary	€ (from m^3 retained)	Hydrological models; damage cost databases	A key ecosystem service with significant public cost implications. Monetisable via avoided damage costs to public infrastructure and emergency services.
	C2	Carbon Sequestration	CBA – Benefit	Monetary	€ (from tCO_2e/year)	Biophysical models; carbon market prices	Directly contributes to climate policy targets. Highly monetisable using carbon market prices or the social cost of carbon.
	C3	Achievement of Strategic Policy Targets	MCDA – Criterion	Quantitative	% objectives achieved	Policy documents; project reports	Measures policy efficiency. An MCDA criterion as it reflects strategic alignment rather than a direct financial flow.
	C4	Job opportunities	MCDA – Criterion	Quantitative	n° job opportunities	Project employment records	A socio-economic co-benefit. Treated as an MCDA criterion because the net social value of temporary green jobs is complex to monetise accurately without a full economic impact study.
	B7	Alignment with SDG Objectives	MCDA – Criterion	Quantitative	n° SDGs	UN SDG framework; project documentation	Demonstrates contribution to global agendas. An MCDA criterion as it represents a qualitative measure of strategic positioning and sustainability leadership.
	B9	Policy / Plan Congruence	MCDA – Criterion	Qualitative	Score [1–3] (local–national relevance)	National and Regional Geoportals; City of Turin – Urban Plans	Assesses the project's fit within the legal and planning context. An MCDA criterion due to its qualitative nature, scored based on expert assessment of plan alignment.

Stakeholder Group	ID	Indicator Name	Type (CBA/MCDA)	Data Type	Unit	Main Data Source	Rationale for Inclusion and Method Assignment
Local Community	D1	Property Value Uplift Attributable to BNG	CBA – Benefit	Monetary	€/m² or % uplift	Academic literature (WTP, Travel Cost); Real estate data	A well-studied, monetisable private benefit arising from proximity to green infrastructure, using hedonic price models.
	D2	Urban Cooling (Heatwave Mitigation)	CBA – Benefit	Monetary	€ (from Δ°C)	Microclimate models; energy price data	A critical health and comfort benefit. Monetisable through reduced energy costs for air conditioning and avoided health costs.
	D3	Recreation Value	CBA – Benefit	Monetary	€/visit or €/year	Academic literature (WTP, Travel Cost)	Captures the direct use value of new green spaces. Monetisable via travel cost method or benefit transfer of willingness-to-pay studies.
	D4	Access to Green Space (% within 300 m)	MCDA – Criterion	Quantitative	% of residents within 300 m	GIS data; census data	A core indicator of environmental justice and equitable distribution of benefits. An MCDA criterion as its value is in achieving a distributional equity target, not a direct monetary gain.
	D5	Inclusion in Decision-Making	MCDA – Criterion	Quantitative	n° stakeholders involved	Municipal participation records	Measures procedural equity and democratic engagement. An MCDA criterion because the value of participation is qualitative and fundamental to social license, not reducible to a monetary figure.
	D6	Social Inclusion and Cohesion	MCDA – Criterion	Quantitative	n° events, participants	ISTAT datasets on social participation	Assesses community-building function. An MCDA criterion, as social capital, is a complex, non-market good measured through proxy metrics like event participation.
	D7	Place Attachment and Cultural Identity	MCDA – Criterion	Qualitative	Score [1–3]	Cultural mapping or heritage databases	Captures intangible cultural value. Inherently qualitative and best handled as a scored MCDA criterion based on community input or expert assessment.

	D8	Opportunities for social relations	MCDA – Criterion	Qualitative	Score [1–3]	Project design documents	Relates to the design's support for social interaction. A qualitative criterion scored based on the presence and quality of social spaces.
	D9	Outdoor activities	MCDA – Criterion	Quantitative	n° different activities supported	Project design documents	A proxy for promoting physical health and active lifestyles. A quantitative MCDA criterion reflecting the diversity of uses provided.
	D10	Places for meditation & psychophysical well-being	MCDA – Criterion	Quantitative	n° dedicated spaces	Project documentation	Addresses mental health and restorative benefits. A quantitative MCDA criterion indicating the provision of spaces specifically designed for quiet contemplation.
	D11	Educational activities	MCDA – Criterion	Quantitative	n° educational programs/features	Project documentation; school partnerships	Measures the project's function as a living laboratory. An MCDA criterion valuing the non-market educational opportunities created.
	D12	Aesthetic perception	MCDA – Criterion	Qualitative	Score [1–3]	Expert landscape assessment; project drawings	A key factor in public acceptance and enjoyment. A qualitative MCDA criterion, as aesthetic value is subjective and best captured through structured scoring.
	D13	Social attractiveness	MCDA – Criterion	Qualitative	Score [1–3]	Project design documents; public space quality assessments	Reflects the project's ability to enhance the area's social vibrancy. A qualitative criterion scored based on design features that encourage visitation and positive social use.

Table 7. Final indicator set for BNG assessment across stakeholders, Author

(Developers, local authorities, and local communities, indicators assigned to CBA or MCDA with units, dimensions, and source)

4.3. Results of the Expert Questionnaire (Validation and Weighting)

4.3.1 Role of Expert Validation for the assessment model

The expert validation process is critical transition for the assessment model, moving from its methodological design (in Chapter 3) to an empirically validated framework. Through a structured validation questionnaire, experts were asked to review the full indicator set in terms of relevance, clarity, and feasibility. This process tested the robustness across a range of professional backgrounds and stakeholder perspectives. Their judgments provide an external check on whether the indicators are conceptually sound, practically measurable, and appropriate for assessing BNG in situations where the 10% BNG requirement is applied, beyond the original UK context.

In parallel, the questionnaire asked each expert to distribute a total of 100 points across all MCDA criteria, deciding how much weight to assign to developer, government and community related indicators. The resulting weights reflect stakeholder-specific strategic priorities. Taken together, the qualitative feedback and quantitative weightings reported in this section implement the proposed validation strategy. This analysis provides a concrete evidence base for refining the indicator set and establishing the final structure of the proposed COSIMA evaluation framework.

4.3.2. Expert Panel Profile and Perspectives

The validation of the BNG indicators was guided by a diverse-background group of four experts. These experts were selected to include a comprehensive viewpoint from academia, policy, and industry practice. This diversity ensures that the indicators are practical across the entire implementation domain and resulting weights reflect real-world decision-making. The panel combines expertise in real estate appraisal, urban and regional planning, local authority environmental planning, and ecology and BNG policy. This range of knowledge is essential because BNG is interdisciplinary, requiring ecological outcomes, planning processes, and economic feasibility to be considered together.

This interdisciplinary panel comprised the following experts:

Marta Dell'Ovo, assistant Professor in Real Estate Appraisal and Valuation at the Department of Architecture and Urban Studies, Politecnico di Milano. Her research in real estate evaluation and multidimensional assessment provides insights into how the indicators capture value creation, investment risk, and the financial robustness of BNG interventions.

Kate Twynham is an ecologist and BNG specialist, working as a Senior Specialist at Natural England and actively involved in the development and implementation of monitoring and evaluation approaches for BNG policy Her work in developing monitoring and evaluation

approaches for BNG policy ensures that the proposed indicators remain coherent with national guidance, statutory requirements, and ecological evidence on biodiversity outcomes.

Benedetta Giudice, assistant Professor in Urban Planning at the Interuniversity Department of Regional and Urban Studies and Planning (DIST), Politecnico di Torino, with research focusing on spatial planning, green infrastructure. she embodies the government, planning, and community perspective, contributing to the evaluation of how BNG-related interventions interact with planning objectives, landscape quality, and experience of urban inhabitants.

Finally, Zain Muhammad is an environmental planner working for the Planning Advisory Service (PAS) in England, where he supports local planning authorities on issues such as BNG implementation. His input reflects a municipality-facing governmental perspective**,** grounded in practical experience with local plan-making, development management, and the operational challenges of applying BNG requirements.

Collectively, this panel combines academic research, national-level policy expertise, and local government practice. The following sections present how their qualitative feedback and quantitative judgments were used to validate the indicator set and derive the stakeholder-specific weights for the assessment model.

Expert	Country	Professional role	Field of expertise
Marta Dell'Ovo	Italy	Real estate academic (Professor)	Real estate evaluation and multidimensional assessment
Kate Twynham	UK	Ecology & BNG policy specialist (Natural England)	Ecology, BNG Policy, Monitoring & Evaluation
Benedetta Giudice	Italy	Urban planning academic (Professor)	Urban and regional planning, green infrastructure
Zain Muhammad	UK	Environmental planner (Planning Advisory Service)	Environmental planning, local authority support, BNG

Table 8. Expert Panel Composition, Author

4.3.3 Qualitative Feedback on Indicators

The qualitative analysis of the expert questionnaire involved a close reading of all written comments by experts, in order to understand how each interviewee perceived the indicators in terms of clarity, relevance and measurability. For each indicator, comments were reviewed and classified as strongly positive, qualified/mixed, or lower priority, depending on whether experts clearly endorsed it, highlighted context-dependence or overlaps, or downplayed its relative importance. Whenever needed, short phrases were retained to illustrate the reasoning behind their judgments.

Overall, three experts (Dell'Ovo, Twynham and Zain) provided qualitative comments. Twynham and Zain offered detailed feedback on most indicators, while Dell'Ovo's remarks were more targeted. Two of experts (Dell'Ovo and Zain) suggested additional indicators. Dell'Ovo proposed Ecosystem services provided (tangible–intangible) for the municipality category and also Zain added four municipality related indicators which are: Protected species/sites, Nature recovery and access, Stakeholder management and the Local planning system.

No indicator was explicitly recommended for exclusion. some indicators such as Government incentives / subsidies or closely related ecosystem-service benefits, were described as context-dependent or overlapping with other indicators, which indicate a need for careful interpretation of the indicators.

The expert comments revealed several consistent themes across stakeholder perspectives. For the developer perspective, the costs of on-site BNG delivery and long-term maintenance are consistently described as highly relevant. All four experts rate on-site delivery (B1) and 30-year maintenance (B5) as High or Very High in importance. One expert emphasised that "tracking the costs associated with on-site delivery is of very high importance to ensure this is proportionate", while another noted that 30-year maintenance is "the main part of the system to ensure appropriate maintenance is secured for the long term".

Off-site delivery cost (B2) is generally considered important for feasibility and viability. three experts rate it High or Very High, while one rates it Moderate and explicitly links its importance to site scale and constraints. Several comments stress that statutory biodiversity credits (B3) should remain a "last-resort option", and that the biodiversity gain site registration fee (B4) is primarily an administrative cost, relevant for project viability but less decisive than delivery and maintenance costs. Suggestions also emerged to reframe on-site delivery costs not purely as an expense, but also as a potential benefit or criterion when they enable more cost-effective or integrated solutions compared to off-site options.

For the municipality perspective, indicators linking BNG to wider strategic objectives receive consistently positive evaluations. Urban flood risk mitigation (C1) and Carbon sequestration (C2) are rated High or Very High by all experts, with comments highlighting their contribution to "multiple benefits and policy targets". Achievement of strategic policy targets (C3) is rated High or Very High by all experts and is described from a government perspective as "extremely important to track… to ensure they are achieving what they have set out to do and using public money wisely".

The new indicators proposed by Zain which is Protected species/sites, Nature recovery and access and Stakeholder management, underline the need to monitor not only aggregate policy outcomes but also the protection of designated assets, the connectivity and accessibility of green

networks, and the governance capacity to manage risks and coordinate actors. The Local planning system indicator is likewise framed as essential to ensure that planning authorities are equipped with the skills and resources to review and enforce BNG requirements effectively.

For the community perspective, experts strongly support indicators related to access, participation and social outcomes. Access to green space (D4) is rated High or Very High by all experts and assigned some of the highest MCDA weights. one comment stressing the “health and wellbeing benefits to communities related to proximity to green spaces” and another noting that proximity must be complemented by actual accessibility.

Inclusion in decision-making (D5) is also considered important, particularly by the policy expert, who describes it as “bringing community and stakeholder perspectives into account in the planning and consultation process”. Social inclusion and cohesion (D6), Opportunities for social relations (D8) and Educational activities (D11) are generally rated Moderate to High ratings. Experts recognized their importance for a comprehensive assessment, even while acknowledging that their quantitative measurement can be challenging.

In contrast, expert views were more divided on other indicators. The importance of Property value uplift (D1) and more subjective measures like Aesthetic perception (D12) and Social attractiveness (D13) ranged from Low to Very High. This divergence suggests these indicators are more context-specific and their relevance may depend heavily on local conditions and values.

4.3.3.1 Indicator-Specific Feedback by Stakeholder Domain

Developers

From the developer perspective, experts consistently identified the cost structure of BNG delivery as the central assessment factor. The cost of on-site delivery (B1) and the 30-year maintenance cost (B5) were repeatedly classified as High or Very High in importance by all experts, reflecting their critical role in determining project feasibility. On-site delivery costs are viewed as a key metric for ensuring that BNG requirements remain proportionate to the scale and constraints of the project, while long-term maintenance is described as the “main part of the system… to ensure appropriate maintenance is secured for the long term”, underpinning the actual success of BNG over the statutory period.

The cost of off-site delivery (B2) and registration fees for gain sites (B4) were also deemed important, though with more variation in ratings (from Moderate to Very High). Experts agreed that these indicators shape developer choices between on-site and off-site options and influence overall project viability, particularly for smaller or more constrained developments. Off-site delivery was described as generally more expensive and complex than on-site provision, making these costs a key determinant of whether off-site solutions are feasible. In contrast, the statutory

biodiversity credit price (B3) was considered more context-dependent and generally assigned Moderate or Low importance. Experts stressed that statutory credits should function as a last-resort mechanism, with their price serving primarily as a signal to discourage development on high-value habitats rather than as a standard cost item in typical BNG delivery pathways.

Opinions on government incentives and subsidies (B6) were likewise nuanced. Ratings ranged from Low to High, and written comments highlighted that, in a strict BNG setting, stacking, bundling and additionally rules limit the direct use of subsidies and grants for mandatory BNG. One expert "would not see this impacting developers too much… rules should prevent the use of subsidies and grants specifically for BNG projects", while still acknowledging that such instruments may be relevant as part of a wider nature-recovery funding landscape.

Among the MCDA criteria, policy and plan congruence (B9) emerged as a particularly important dimension. It is consistently rated High or Very High and assigned non-negligible weights, indicating that it plays a substantive role in structuring developer preferences. Experts emphasised that alignment between BNG requirements and other planning or environmental policies can reduce administrative burdens and enable the delivery of multiple co-benefits, for example by combining BNG measures with sustainable drainage systems

BNG uplift ambition (B8) occupies an intermediate position. It was positively received, especially by planning-oriented experts, who see it as a valuable indicator for tracking whether developers exceed the statutory 10% requirement and how any additional uplift is managed. However, its importance was rated Very High by one expert but only Low–Moderate by others, and its weights are substantial in some responses but not dominant across the panel. In particular, the UK-based experts tended to treat uplift beyond the mandatory 10% as an "extra" contribution rather than a core compliance requirement; for them, additional uplift is desirable but often constrained by feasibility and viability considerations, which explains why B8 receives only moderate scores despite being conceptually appreciated.

By contrast, alignment with SDG objectives (B7) was recognised as conceptually relevant but generally assigned Moderate or Low importance. Experts noted that SDGs provide a high-level sustainability framework and may be used for communication or reputational purposes; however, they are seen as "more likely to be important for policy makers and government" and as considerations that should already be embedded in organisational strategies rather than driving project-level trade-offs.

Local Authority/Municipality

From the government and municipal perspective, experts converged on the importance of indicators that link BNG to broader public policy objectives and ecosystem-service outcomes.

Urban flood risk mitigation (C1) and carbon sequestration (C2) were consistently rated High or Very High, reflecting their central role in addressing climate-change adaptation and mitigation targets. Comments emphasised that these benefits are tightly intertwined with more general nature-recovery functions, suggesting the need to interpret them within an integrated ecosystem-services logic and to consider potential overlaps with other indicators when aggregating results.

The MCDA criterion *achievement of strategic policy targets* (C3) was identified as a core indicator for governments. Experts highlighted that it captures whether BNG effectively contributes to city- or region-level objectives (e.g. climate, biodiversity, health, equity) and whether public resources and regulatory efforts are delivering the intended outcomes. One expert described it as "extremely important to track… to ensure they are achieving what they have set out to do and using public money wisely", confirming its role as a central policy performance measure. *Job opportunities* (C4) was also considered important, reflecting economic co-benefits such as new employment in ecological restoration and monitoring, upskilling of professionals, and the closing of capacity gaps within local authorities and consultancies.

The validation process also led to the addition of new municipality-level indicators, which enrich the original framework. A real-estate expert proposed an explicit ecosystem-services indicator (C5 – Ecosystem services provided) to capture the full range of tangible and intangible benefits delivered to communities by enhanced biodiversity. in her weighting, this criterion received very high importance. An environmental planning expert introduced three further criteria focusing on *Protected species/sites* (C5 – Protected species/sites), *Nature recovery & access* (C6) and the *Local planning system* (C8). These additions emphasise, respectively, the protection of designated conservation assets and priority species, the role of BNG in reinforcing a wider, accessible green-infrastructure network for people and wildlife, and the institutional capacity of local planning authorities to review, enforce and monitor BNG requirements.

Local Communities

For local communities, expert feedback strongly confirmed the central role of indicators related to access, equity and everyday well-being. Access to green space within 300 m (D4) emerged as one of the most important criteria across the entire framework. it was consistently rated High or Very High and received some of the highest MCDA weights. Experts underscored its direct connection to physical and mental health, environmental justice and the lived experience of residents, noting that proximity and actual accessibility must both be taken into account. Inclusion in decision-making (D5) was likewise highlighted as a key procedural indicator, capturing the extent to which community voices influence the planning and delivery of BNG. It

was described as essential to ensure legitimate, context-sensitive implementation and to embed stakeholder perspectives into project design.

The more outcome-oriented indicators Social inclusion and cohesion (D6) and Opportunities for social *relations* (D8) were generally rated positively, with lower priority than access and participation. They are seen as important elements within a broader cluster of social benefits, indicating how BNG interventions may support social mixing, cohesion and informal interactions in public spaces, even if these effects are more difficult to quantify. Experts also gave favourable assessments to indicators capturing recreational, health and cultural dimensions. Urban cooling (heatwave mitigation) (D2) and Recreation value (D3) were considered important for climate resilience and social well-being; one expert explicitly noted that any valuation of recreation should be combined with an explicit consideration of accessibility, reinforcing the link to D4. Property value uplift attributable to BNG (D1) was viewed as relevant, especially for owner-occupiers, but more context-specific for rental markets, and is therefore treated as a benefit whose salience may vary with tenure structure.

Finally, indicators such as Educational activities (D11), Aesthetic perception (D12) and Social attractiveness (D13) were recognised as meaningful for understanding how BNG influences environmental awareness, place image and the perceived quality and vibrancy of neighborhoods. *Place* attachment and cultural identity (D7) and Places for meditation and psychophysical well-being (D10) were judged conceptually relevant but more specific and subject to local value judgements. They were therefore retained as complementary indicators that help capture the less tangible yet significant experiential aspects of BNG outcomes, particularly in contexts where cultural identity or mental-health benefits are a specific focus.

These expert reflections, summarised, offer a qualitative foundation that complements the following quantitative data. This narrative explains the reasoning behind the indicator selection for the assessment framework.

A table of experts comments is provided in Appendix A, which provides a comprehensive summary of expert comments and revision decisions, the majority of indicators received consistently positive evaluations and were retained in the framework. A smaller subset was treated as context-dependent or conceptually merged into broader clusters to avoid redundancy. The new indicators proposed by experts significantly strengthening the governmental dimension of the model.

4.3.4. Quantitative Results: Likert-Scale Validation of Indicators

The quantitative analysis of Likert-scale scores complements the qualitative comments by providing a concise statistical picture of how strongly each stakeholder domain is prioritised by

the experts. It is used here to identify where there is clear convergence on the importance of certain indicators and where views are more differentiated or context-dependent. Figure 4.X summarises the average importance assigned by each expert to the three stakeholder domains. For all respondents, municipality-related indicators receive the highest average scores (between 4.25 and 4.80 on a 1–5 scale), followed by developer and community indicators. Benedetta Giudice and Marta Dell'Ovo put strong emphasis on municipal criteria (4.50 and 4.80 respectively). Kate Twynham's evaluations are more balanced across the three domains, with slightly higher scores for municipality indicators. Zain Muhammad adopts a more cautious scoring pattern overall, but still rates municipality indicators above 3.8, confirming the perceived importance of local authority roles in implementing the 10% BNG target.

Perspective	Benedetta Giudice	Kate Twynham	Marta Dell'Ovo	Zain Muhammad
Developer	4.11	3.78	3.56	3.00
Municipality	4.50	4.25	4.80	3.88
Community	3.62	3.77	3.77	3.00

Table 9. Average importance score per expert and stakeholder domain, Author

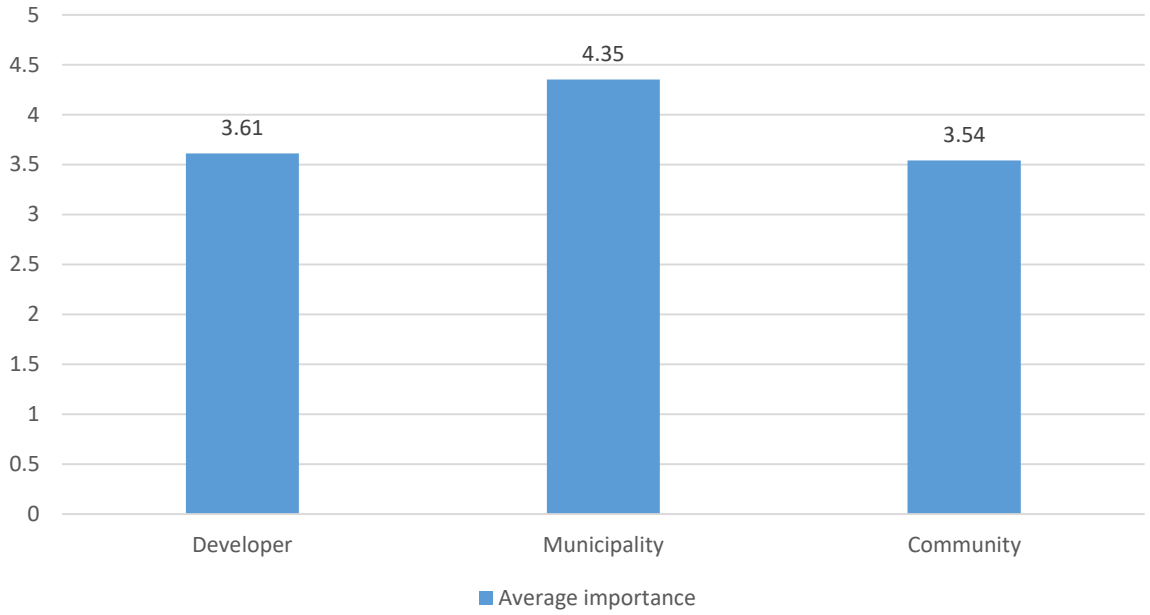


Figure 16. Average importance per expert and stakeholder domain, Author

4.3.4.1 Aggregate Statistics for CBA and Validation Indicators

For the CBA indicators, the Likert-scale judgements of the experts were converted into numerical scores from 1 (very low) to 5 (very high), using the Indicators importance score column in the survey file. For each indicator and stakeholder domain, descriptive statistics were computed across the four experts (mean, median and standard deviation), in order to summarise both the central tendency and the dispersion of the feedbacks. In cases of newly introduced indicators of Nature Recovery and Access indicator we only have one experts rating. The following tables report the results separately for CBA indicators of each stakeholder group. Indicators with high mean values and low standard deviations will be interpreted as strongly and consistently supported, whereas lower means or higher dispersion will be considered more context-dependent.

The quantitative results for developer-related CBA indicators confirm a strong consensus on core cost items. On-site delivery costs (B1) and long-term maintenance (B5) show high mean values with low standard deviations, underscoring their undisputed centrality. Off-site delivery cost (B2) also has a high mean, but its larger standard deviation indicates that while generally important, its relevance is more dependent on specific project contexts.

In contrast, the statutory credit price (B3) and registration fee (B4) present more moderate mean scores. B3's low dispersion signals broad agreement on its secondary importance, while B4's higher variability confirms its more context-dependent role. Finally, government incentives and subsidies (B6) exhibit an intermediate mean with considerable dispersion, quantitatively reinforcing the qualitative view that their relevance is confined to specific policy settings.

ID	Indicator	Mean importance	Median	Std. dev.	Min	Max	n (experts)
B1	Cost of BNG Delivery (On-site) / GI Delivery	4.75	5.00	0.50	4.00	5.00	4
B2	Cost of BNG Delivery (Off-site)	4.25	4.50	0.96	3.00	5.00	4
B3	Statutory Biodiversity Credit Price (proxy for IT)	2.75	3.00	0.50	2.00	3.00	4
B4	Biodiversity Gain Site Registration Fee (proxy for IT)	3.25	3.25	0.96	2.00	4.00	4
B5	Maintenance Cost (30-year)	4.50	4.50	0.58	4.00	5.00	4
B6	Government Incentives / Subsidies	3.25	3.25	0.96	2.00	4.00	4

Table 10. Descriptive Statistics for Developer CBA Indicators, Author

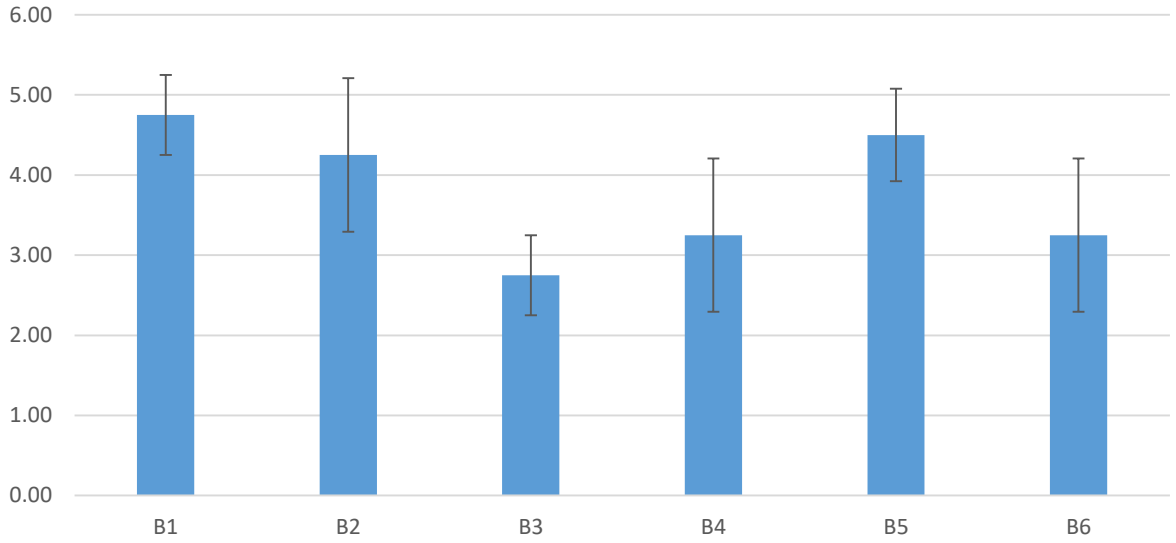


Figure 17. Mean Importance Scores of Developer CBA Indicators (with Standard Deviations), Author

Municipality-level CBA indicators are consistently rated as highly important. Flood-risk mitigation (C1) and carbon sequestration (C2) both achieve mean scores above 4.2 with limited dispersion, confirming their role as key public benefits associated with BNG. The newly introduced Nature Recovery and Access indicator (C6) also receives a high importance score from the expert who proposed it, reinforcing the idea that BNG should be understood as part of a broader, accessible green-infrastructure network, even if further validation with additional experts would be desirable.

ID	Indicator	Mean importance	Median	Std. dev.	n (experts)
C1	Urban Flood Risk Mitigation	4.50	4.50	0.58	4
C2	Carbon Sequestration	4.25	4.00	0.50	4
C6*	Nature Recovery & Access (added ex novo)	4.00	4.00	0.00	1

Table 11. Descriptive Statistics for Municipality CBA Indicators, Author

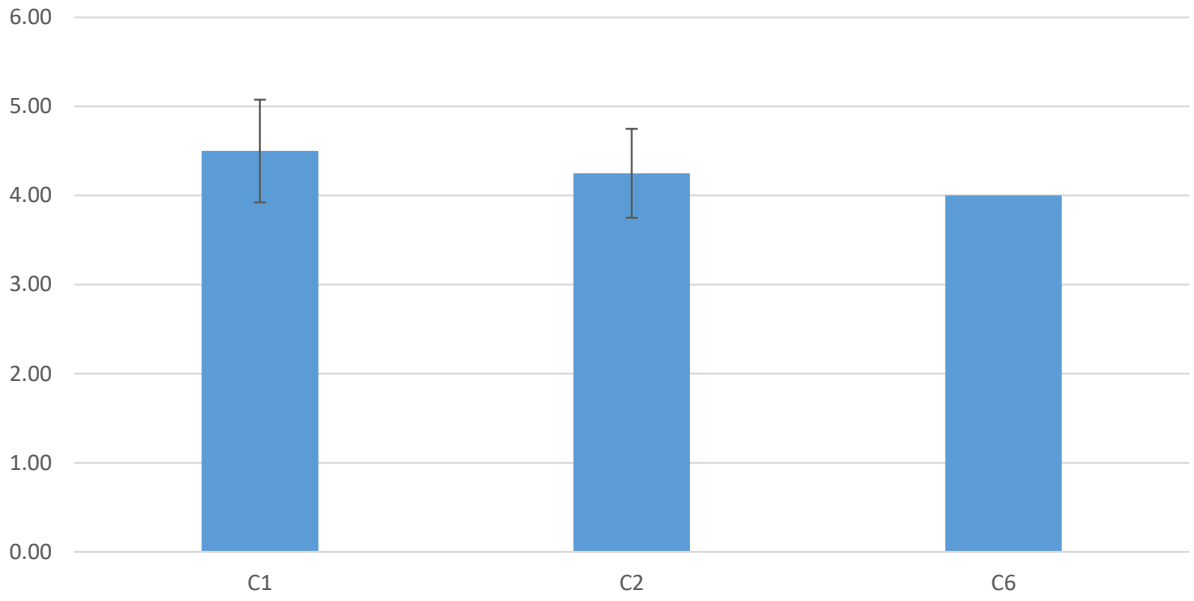


Figure 18. Mean Importance Scores of Municipality CBA Indicators (with Standard Deviations), Author

For the community perspective, experts converge on the importance of climate and well-being related benefits, with Urban Cooling (D2) and Recreation Value (D3) both showing means around or above 3.75 and relatively low variability. Property value uplift (D1) has a more moderate mean and the highest standard deviation (1.29), indicating divergent views on how central this economic benefit is, particularly when comparing owner-occupied and rental housing contexts.

ID	Indicator	Mean importance	Median	Std. dev.	n (experts)
D1	Property Value Uplift Attributable to BNG	3.50	3.50	1.29	4
D2	Urban Cooling (Heatwave Mitigation)	4.00	4.00	0.82	4
D3	Recreation Value	3.75	4.00	0.50	4

Table 12. Descriptive Statistics for Community CBA Indicators, Author

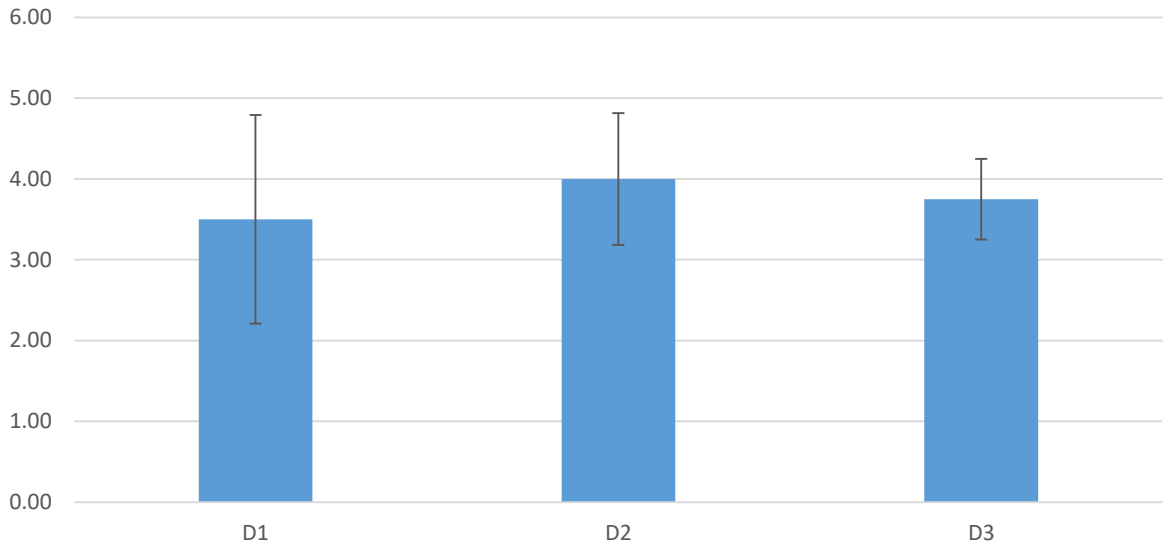


Figure 19. Mean Importance Scores of Community CBA Indicators (with Standard Deviations), Author

For the developer perspective (Table10, Figure 15), the quantitative results confirm a strong consensus on core cost items. On-site delivery costs (B1) and long-term maintenance (B5) show high mean values with low standard deviations, underscoring their undisputed centrality. Off-site delivery cost (B2) also has a high mean, but its larger dispersion indicates that, while generally important, its salience varies with project context. In contrast, the statutory credit price (B3), registration fee (B4) and government incentives and subsidies (B6) exhibit more moderate means and, in some cases, higher variability, quantitatively reinforcing the qualitative view that these indicators are relevant but more scenario-specific.

For the community perspective (Table 11, Figure 16), experts converge on the importance of climate- and well-being-related benefits. Urban cooling (D2) and recreation value (D3) exhibit relatively high mean scores with limited dispersion, indicating broad agreement that these benefits are central to how residents experience BNG. Property value uplift attributable to BNG (D1) shows a more moderate mean and the highest standard deviation among the community indicators, pointing to divergent views on the relevance of strictly monetary gains for residents, particularly when distinguishing between owner-occupied and rental housing contexts.

The descriptive statistics from the Likert-scale ratings were then used to distinguish, for each stakeholder group, between core and context-dependent CBA indicators. Indicators with high mean importance and low standard deviation were treated as clearly validated by the expert panel, whereas those with lower averages and/or higher dispersion were considered secondary or optional. Applying this rule confirms that eight indicators, B1, B2, B5, C1, C2, C6, D2 and D3, form the core CBA layer of the COSIMA framework, while four indicators, B3, B4, B6 and D1, are

retained as context-specific complements. These optional indicators become particularly relevant in credit-heavy delivery contexts, where the 10% BNG target is achieved mainly via purchased credits and credit-related cost items gain prominence. Conversely, in scenarios that emphasise on-site enhancement, the focus shifts towards on-site delivery and long-term maintenance (B1, B5) together with municipality and community benefits (C1, C2, C6, D2, D3), which capture local ecosystem-service gains and co-benefits for residents. Overall, no CBA indicator is fully discarded, but the Likert results and expert comments clearly separate those that should enter every COSIMA application from those activated only when supported by policy context and data availability.

4.3.5. Quantitative Results: MCDA Criteria Weighting

In the MCDA module, each expert was asked to allocate 100 points across all MCDA criteria, expressing their perceived relative importance. To reduce cognitive load and avoid excessively fragmented allocations, this exercise was restricted to a maximum of ten "top" criteria per expert, so the total number of weighted indicators is lower than the full conceptual list presented in Chapter 3. For the analysis, the weights were first aggregated by all stakeholder domain and normalised so that, for each expert, the sum of weights equals 100 points, making results comparable across respondents. Criteria that were not selected by a given expert were assigned a weight of zero, which represents absence of selection in the prioritisation task, not an explicit rejection of the indicator. Descriptive statistics (mean, minimum, maximum and standard deviation) were then calculated for each criterion to summarise central tendencies and variability. The final validation of the MCDA criteria set was not determined mechanically by numerical ranking, but derived through a critical synthesis of these quantitative patterns with the Likert-scale importance scores, written expert comments and insights from the literature. This is a deliberate methodological choice, ensuring that the resulting COSIMA criteria reflect both empirical priorities and the broader conceptual rationale of the framework.

4.3.5.1. Aggregate MCDA Weights: Means, Variability, and Order of Rankings

For the MCDA criteria, each expert distributed a single total of 100 points across the entire set of indicators. The individual allocations were then aggregated to obtain an overall picture of priorities. The weights were first normalised and the sum of the all MCDA criteria equals 100 points. Criteria that were not selected by an expert were assigned a weight of zero for the aggregate calculations.

For every indicator, descriptive statistics (mean, standard deviation, minimum and maximum) were computed to summarise how experts distributed their weights. Within the developer-related criteria, Policy / Plan Congruence (B9) clearly emerges as the most consistently prioritised indicator, suggesting broad agreement that aligning BNG schemes with local planning

requirements is a central concern for developers. BNG Uplift Ambition (B8) also attracts a substantial share of the weights, but with greater variation across experts, indicating that its perceived importance depends on how strongly different contexts encourage going beyond the minimum BNG baseline. By contrast, Alignment with SDG Objectives (B7) receives only marginal weight in most allocations, implying that it is viewed as peripheral in strictly developer-focused assessments and more relevant at higher strategic or policy scales than at the individual project level.

ID	Criterion	Mean weight	Std. Dev.	Min	Max
B9	Policy / Plan Congruence	11.93	2.28	9.62	15.00
B8	BNG Uplift Ambition	10.79	4.46	5.00	15.00
B7	Alignment with SDG Objectives	0.96	1.93	0.00	3.85

Table 13. Expert-Elicited Weights for Developer-Related MCDA Criteria, Author

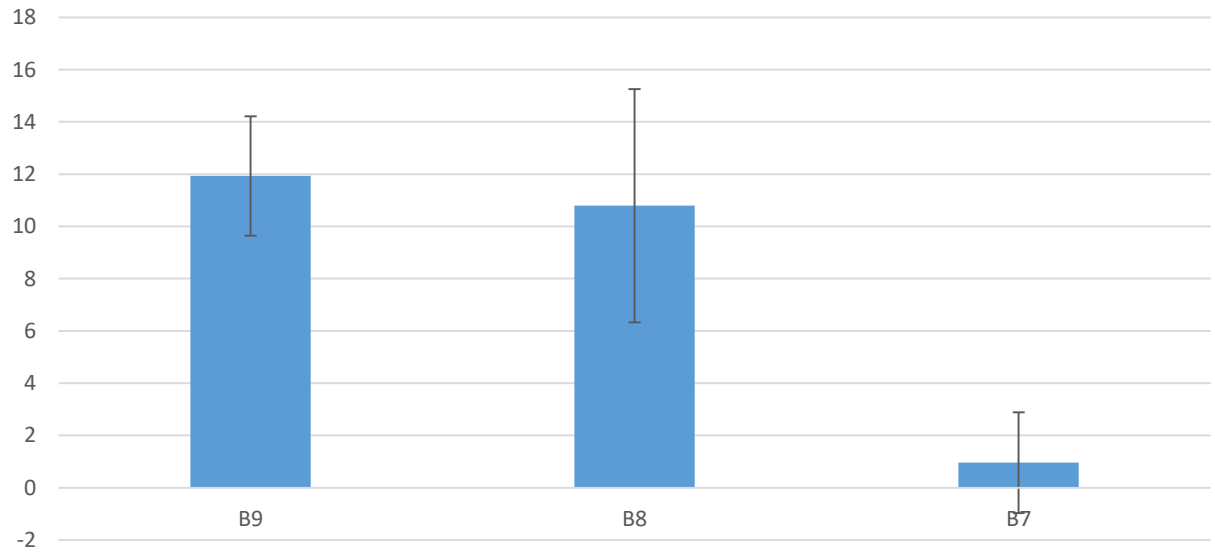


Figure 20. Weight Allocation Patterns for Developer MCDA Criteria, Author

For the municipality domain, Ecosystem Services Provided (C5) and Achievement of Strategic Policy Targets (C3) attract the largest shares of the weights, indicating that experts generally see these as central to the public-sector assessment of BNG. At the same time, the dispersion of weights across experts is relatively high, reflecting different views on how strongly BNG should be tied to measurable ecosystem-service outcomes versus formal policy targets. Secondary criteria such as Local Planning System (C8), Job Opportunities (C4) and Stakeholder Management (C7) receive comparatively low average weights, suggesting that institutional-capacity and stakeholder-governance considerations are important for some experts but are not uniformly

prioritised across the panel. It is also noteworthy that some of these criteria (particularly C5, C7 and C8) were originally proposed by individual experts; for those criteria, non-introducing experts effectively assign a weight of zero, which mechanically increases the observed variation in the aggregate results.

ID	Criterion	Mean weight	Std. Dev.	Min	Max
C5	Ecosystem Services provided (tangible–intangible)	9.55	10.82	0.00	25.00
C3	Achievement of Strategic Policy Targets	8.10	6.99	0.00	17.00
C8	Local Planning System	2.59	4.84	0.00	10.35
C4	Job Opportunities	2.94	3.94	0.00	10.00
C7	Stakeholder Management	1.52	3.04	0.00	6.07

Table 14. Expert-Elicited Weights for Municipality Related MCDA Criteria, Author

(C5_ES is the "Ecosystem services provided" criterion added by Marta, C7 and C8 are the criteria added by Zain. Non-added experts contribute a weight of 0 in the stats.)

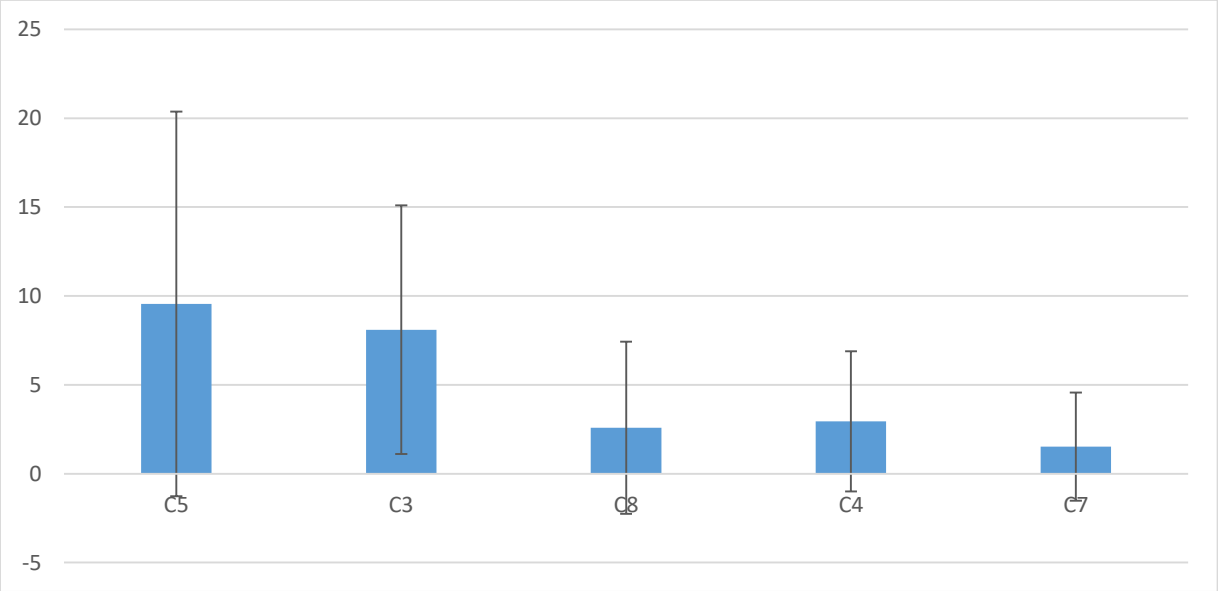


Figure 21. Weight Allocation Patterns for Municipality MCDA Criteria, Author

For the community domain, Access to Green Space (% within 300 m) (D4) clearly stands out as the most heavily weighted criterion, pointing to a strong and broadly shared view that physical accessibility to green areas is the cornerstone of community-level BNG benefits. Social Inclusion and Cohesion (D6) and Inclusion in Decision-Making (D5) receive intermediate but still substantial weights, indicating that experts widely recognise their importance, even if they differ on how prominently these social aspects should feature relative to other criteria. The remaining community indicators, such as Educational Activities (D11), Social Attractiveness (D13), Aesthetic

Perception (D12) and the more specific experiential criteria D7–D10 attract more modest average weights and display greater variation across experts. This pattern suggests that they are viewed as valuable but more context-dependent, and therefore more suitable as complementary rather than core indicators within the framework. The fact that some criteria (notably D9 and D10) were effectively not used in the weighting exercise further supports their interpretation as optional, context-specific additions rather than central elements of the community assessment.

ID	Criterion	Mean weight	Std. Dev.	Min	Max
D4	Access to Green Space (% within 300 m)	16.09	3.19	12.11	19.23
D6	Social Inclusion and Cohesion	7.81	5.27	0.00	11.54
D5	Inclusion in Decision-Making	8.49	8.11	0.00	18.00
D11	Educational Activities	5.64	6.51	0.00	11.54
D13	Social Attractiveness	5.39	6.25	0.00	11.54
D12	Aesthetic Perception	3.75	4.79	0.00	10.00
D7	Place Attachment and Cultural Identity	2.44	4.88	0.00	9.76
D8	Opportunities for Social Relations	1.25	2.50	0.00	5.00
D9	Outdoor Activities	0.00	0.00	0.00	0.00
D10	Places for Meditation & Psychophysical Well-being	0.00	0.00	0.00	0.00

Table 15. Expert-Elicited Weights for Community Related MCDA Criteria, Author

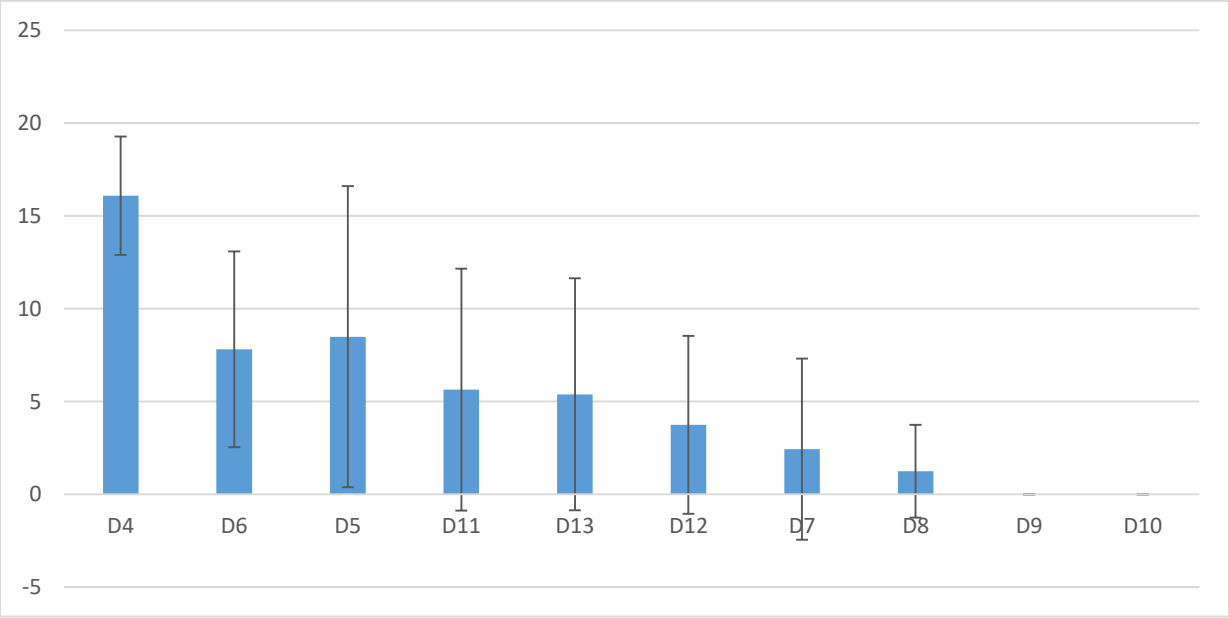


Figure 22. Weight Allocation Patterns for Community MCDA Criteria, Author

Overall, the aggregate MCDA results identify a compact set of consistently important criteria most notably B9 (and to a lesser extent B8) for developers, C5 and C3 for government, and D4 (together with D5–D6) for communities, while clearly separating a second group of indicators whose lower means and higher variability point to a more optional, scenario-dependent role in the final COSIMA model.

4.3.5.2 Stakeholder-Domain Priorities in MCDA Weights

Figure 21, compares the relative emphasis that each expert gives to the three stakeholder domains (Developers, Municipality, Communities). For each expert, the total normalised MCDA weight was summed by stakeholder group. The radar chart shows that Expert A allocates nearly 60% of their weight to community-related criteria. Expert B similarly concentrates on community criteria but assigns a larger share to municipal indicators. Expert C places comparatively more emphasis on government/municipal criteria, while Expert D distributes weights more evenly across the three domains. Overall, the figure confirms that, although all experts recognise the importance of community outcomes, their relative focus on developer versus government perspectives varies, reflecting their professional backgrounds.

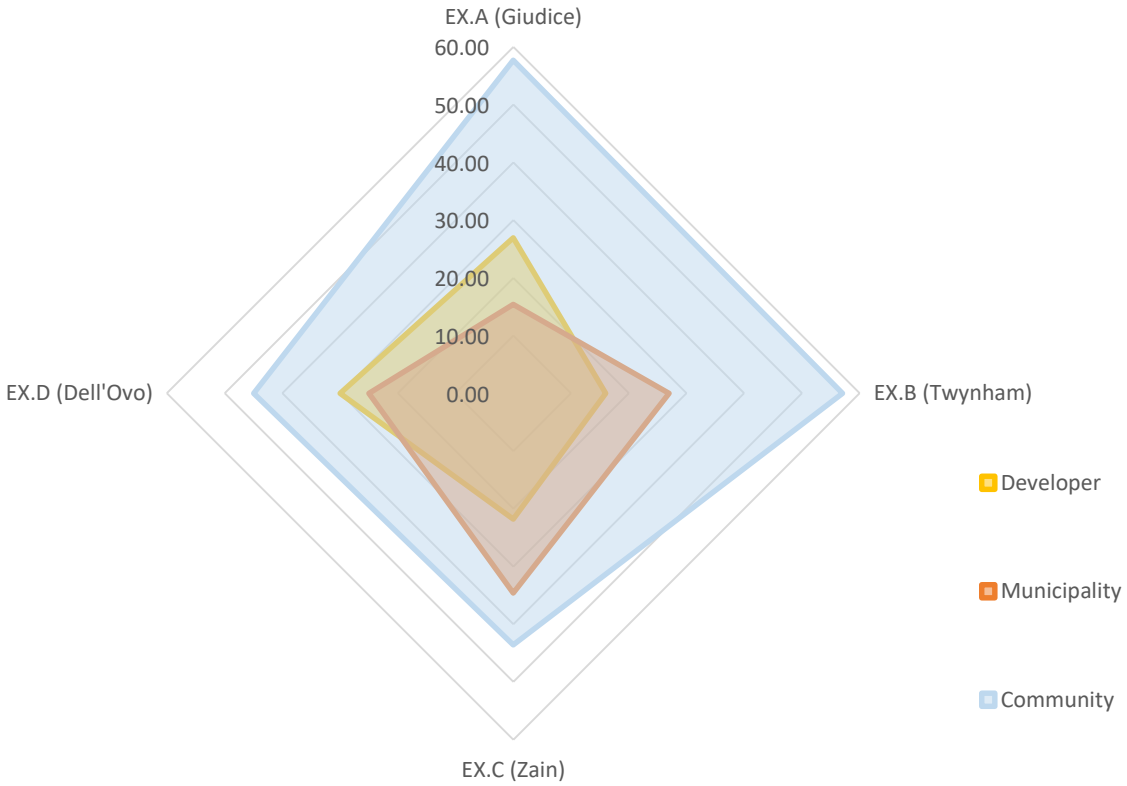


Figure 23. Relative distribution of MCDA weights across the three stakeholder domains for each expert, Author

4.3.6. Cross-Analysis and Definition of the Core Validated Indicator Set

The final selection of indicators for the assessment framework of this study is based on a cross-analysis that combines the two quantitative dimensions developed in the previous sections:

- the relevance and feasibility scores obtained from the Likert-scale validation, and
- the strategic importance expressed through the MCDA weights.

For each indicator, the mean Likert rating (and its dispersion) was compared with the mean MCDA weight and ranking within the corresponding stakeholder domain. Indicators with consistently high Likert scores and high average MCDA weights are interpreted as part of the core validated indicator set, since they are simultaneously perceived as relevant, measurable and strategically central. At the opposite end, indicators with low or moderate Likert scores and negligible or zero MCDA weights are treated as secondary or optional, and in a few cases are merged with other indicators to avoid redundancy. Intermediate cases with mixed signals (e.g. high Likert importance but high disagreement, or high relevance but relatively low weights) are resolved through interpretative judgement, taking into account conceptual clarity, measurability and alignment with the COSIMA logic.

Table 16, summarises the outcome of this cross-analysis for a selection of representative indicators. Developer-related indicators such as B1 Cost of BNG Delivery (on-site) and B5 Maintenance Cost (30-year) combine very high average Likert scores with strong consensus and are therefore classified as core CBA inputs. In the MCDA layer, B9 Policy / Plan Congruence and B8 BNG Uplift Ambition show the highest mean weights among developer criteria, confirming their central role in capturing regulatory clarity and ambition. On the governmental side, C1 Urban Flood Risk Mitigation and C2 Carbon Sequestration display high Likert means and low standard deviations, while C3 Achievement of Strategic Policy Targets and the added C5 Ecosystem Services provided rank at the top of the municipality MCDA weights. For communities, D2 Urban Cooling, D3 Recreation Value and D4 Access to Green Space are consistently rated as highly important, and D4 and D5 Inclusion in Decision-Making receive the largest MCDA weights, placing them in the heart of the core set.

By contrast, indicators such as B3 Statutory Biodiversity Credit Price, B4 Biodiversity Gain Site Registration Fee, B6 Government Incentives/Subsidies and D1 Property Value Uplift have more moderate Likert means and are never given prominent MCDA weights. They are retained as supportive or scenario-specific indicators, relevant particularly in contexts where the 10 % BNG target is achieved mainly through credits (e.g. B3 and B4) or where financial incentives and property markets are explicitly under scrutiny (B6, D1). Similarly, community indicators on outdoor activities (D9) and places for meditation and psychophysical well-being (D10) show comparatively low importance scores and no MCDA weights; their underlying functions are

largely captured by broader recreation, health and social-cohesion indicators, so they are treated as redundant and merged conceptually into D2, D3 and D6 rather than kept as standalone criteria.

These distinctions also allow the model to reflect different BNG application scenarios. In credit-based delivery situations, where the 10 % BNG uplift is achieved mainly through off-site credits, the credit-related cost indicators (B3, B4) become more prominent, while on-site habitat enhancement costs may play a secondary role. In on-site enhancement scenarios, the emphasis shifts towards B1, B2 and especially B5, together with municipality and community benefits such as C1, C2, C5, D2 and D3, which capture local ecosystem services and co-benefits for residents. The cross-analysis therefore does not impose a single rigid ranking, but rather identifies a core backbone of indicators that should be present in all applications and a flexible set of supportive indicators that can be activated depending on the delivery context and data availability.

Indicator code	Mean Likert rating	Mean MCDA weight	Cross-analysis classification	Final decision
B1	Very high, low SD	-	Core CBA indicator (cost)	Include as mandatory CBA input (on-site cost)
B2	High–very high	-	Core CBA indicator (cost)	Include as mandatory CBA input (off-site cost)
B3	Moderate, low SD	-	Supportive / scenario-specific	Include as optional CBA input in credit-based scenarios
B4	Moderate	-	Supportive / scenario-specific	Include as optional, merged with overall off-site transaction costs
B5	High–very high, low SD	-	Core CBA indicator (long-term)	Include as mandatory CBA input (30-year maintenance)
B8	High for most experts	High mean	Core MCDA criterion	Include as MCDA criterion (developer ambition)
B9	High	Highest mean	Core MCDA criterion	Include as MCDA criterion (policy congruence)
C1	Very high, low SD	-	Core CBA benefit	Include as mandatory CBA input (flood-risk mitigation)
C2	High–very high	-	Core CBA benefit	Include as mandatory CBA input (carbon sequestration)

C3	High	High mean	Core MCDA criterion	Include as MCDA criterion (strategic policy targets)
C5 (ES)	Very high (for the expert)	High weight (municipality)	Core MCDA criterion	Include as MCDA criterion for ecosystem services; check overlap with C1–C2
D2	High	-	Core CBA benefit	Include as mandatory CBA input (urban cooling)
D3	High	-	Core CBA benefit	Include as core CBA input (recreation value)
D4	Very high, low SD	Highest MCDA weight	Core MCDA criterion	Include as key MCDA criterion (access to green space)
D5	Very high for most experts	High mean weight	Core MCDA criterion	Include as MCDA criterion (inclusion in decision-making)
D6	High–moderate	Substantial mean weight	Core/supportive MCDA criterion	Include as MCDA criterion (social cohesion)
D1	Moderate, high SD	0	Supportive economic indicator	Include as optional CBA input in property-market analyses
D9	Moderate–low, no weighting	0		Merged conceptually into recreation and health indicators (D2–D3)
D10	Moderate–low, no weighting	0		Merged into broader well-being and cultural indicators (D6, D7, D12)

Table 16. Cross-analysis of selected indicators: Likert validation vs MCDA weighting, Author

On the basis of this cross-analysis, the core validated set of indicators comprises approximately eighteen indicators (about seven CBA inputs and eleven MCDA criteria) that show both high relevance and strong or at least consistent weighting across experts. A further group of roughly nine indicators is retained as supportive or context-dependent, to be used selectively depending on whether the BNG target is pursued mainly through on-site enhancement, off-site gains or statutory credits, and on data availability. Finally, five indicators are effectively merged or relegated to optional status due to conceptual overlap or weak perceived relevance. Importantly, no indicator is discarded purely on the basis of a numerical threshold: inclusion or exclusion is always justified by the combination of quantitative evidence and qualitative reasoning, and by

the need to maintain conceptual clarity, practical measurability and coherence with European/Italian BNG implementation contexts within the COSIMA framework.

4.3.6.1 Final MCDA Indicator Set and Normalised Weights

Table 17, presents the final MCDA criteria retained in COSIMA and their associated weights. For each expert, 100 points were distributed across all MCDA criteria jointly (i.e. across all stakeholder perspectives), and these scores were then averaged across experts. The column "Mean weight (0–100)" reports these average scores on the original 0–100 scale. To obtain a consistent weighting structure for the final model, the mean weights of the retained criteria were then normalised over the whole set of MCDA indicators, so that their sum equals 1 (or 100 %) overall, rather than within each stakeholder group. The "Normalised weight" and "Normalised weight (%)" columns report these rescaled values and can be directly used in COSIMA applications.

Perspective	**ID**	**Criterion**	**Mean weight (0–100)**	**Normalised weight**	**Normalised weight (%)**
Developer	B9	Policy / Plan Congruence	11.93	0.164	16.4
Developer	B8	BNG Uplift Ambition	10.79	0.148	14.8
Municipality	C5	Ecosystem Services provided (tangible–intangible)	9.55	0.131	13.1
Municipality	C3	Achievement of Strategic Policy Targets	8.10	0.111	11.1
Community	D4	Access to Green Space (% within 300 m)	16.09	0.221	22.1
Community	D5	Inclusion in Decision-Making	8.49	0.117	11.7
Community	D6	Social Inclusion and Cohesion	7.81	0.107	10.7

Table 17. Final MCDA criteria and normalised weights for COSIMA, Author

These normalised weights preserve the relative priorities expressed by the experts while ensuring that the final COSIMA model uses a single, coherent weighting system across all MCDA indicators. At the same time, the structure remains flexible: in future applications, the normalised weights can be updated or re-estimated if local stakeholders or decision-makers wish to express different preferences or policy priorities.

4.4 Evaluation Framework

The development and validation of the indicator set in the previous sections respond to the overarching aim of this thesis to construct a coherent, stakeholder-sensitive framework for assessing the multi-dimensional impacts of mandatory BNG. Having identified which costs, benefits and strategic criteria are most relevant for developers, public authorities and local communities, the next step is to clarify how such information could, in principle, be organised within an integrated evaluation logic. The following section therefore presents the COSIMA model as a conceptual assessment framework. Rather than applying the model empirically, the thesis uses COSIMA to illustrate how monetary and non-monetary indicators, together with their validated weights, could be combined into a unified structure for future BNG appraisals, thereby linking the indicator work to a broader decision-analytic perspective.

4.4.1. The COSIMA Assessment Model

To address the multidimensional impacts of BNG implementation across economic, environmental, and social dimensions, this study adopts the COSIMA framework. This model, pioneered by Barfod and Salling (2015) and effectively applied in ecosystem services assessments by Oppio et al. (2024), provides a robust structure for integrating quantitative monetary valuation with qualitative multi-criteria analysis.

The core reason of considering COSIMA for this study is that a comprehensive evaluation of policies like BNG requires a hybrid approach. While Cost-Benefit Analysis effectively captures monetizable impacts, it often under-represents intangible social and environmental values. On the other hand, Multi-Criteria Decision Analysis is excellent at structuring these non-monetary aspects but lacks the direct economic interpretability of CBA. COSIMA synthesizes these two methodologies, applying them in parallel and aggregating their results into a single, holistic index of project performance.

4.4.2. Model Structure and Formula

The COSIMA model calculates a Total Rate of Return (TRR) for each alternative scenario, which represents the overall value generated per unit of cost, considering both monetary and strategic non-monetary impacts. The TRR for an alternative *Ak* is given by the following equation (adapted from Barfod & Salling, 2015; Oppio et al., 2024):

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

Where:

Ak: Represents the alternative scenario being evaluated (e.g., Baseline, Development without BNG, Development with BNG).

TV(Ak): The Total Value of alternative k, an aggregate measure of all benefits.

Ck: The Total Cost of alternative k, encompassing investment and discounted maintenance costs over the project's lifetime (e.g., 30 years for BNG).

Vi(Xik): The monetary value of CBA impact ii for alternative k. This is the Net Present Value (NPV) of all monetized benefits for that stakeholder group.

VFj(Yjk): The value score for alternative k under MCDA criterion j, derived from standardized performance scores.

wj: The weight reflecting the relative importance of MCDA criterion j, derived from expert/stakeholder input.

$\alpha\alpha$: The trade-off parameter, a scaling factor that determines the relative influence of the MCDA component compared to the CBA component in the final Total Value. It allows for sensitivity analysis, testing how the results change when more or less weight is given to strategic, non-monetary criteria (e.g., from α=0%α=0%, pure CBA, to α=100%α=100%, full integration).

4.4.3. Integration of CBA and MCDA within COSIMA

The application of CBA and MCDA within the COSIMA framework is designed to be complementary and non-redundant.

The CBA Module: This module quantifies all impacts that can be credibly expressed in monetary terms. For this study, it includes costs to developers (e.g., delivery, credits, maintenance) and monetized benefits to government and society (e.g., recreation value, health gains, flood risk reduction) calculated using benefit transfer methods and modeling tools like InVEST.

The MCDA Module: This module captures the strategic, non-monetary impacts that are difficult or controversial to monetize. It is structured using Multi-Attribute Value Theory (MAVT). The process involves:

Criteria Selection:

As it has been done, a set of criteria based on the literature review and policy gaps (e.g., well-being, access to green space, policy congruence). The foundation of a robust MCDA is a comprehensive and logically structured set of criteria. For this study, the MCDA criteria are organized into a hierarchical Value Tree, which translates the overarching goal of assessing increase in biodiversity into measurable indicators.

The top-level goal is BNG Impact, which is decomposed into five main strategic criteria:

- Environmental Effect: Assessing the environmental impact of increased biodiversity in an urban context.
- Social and economic impact: Quantifying the project's consequences on community welfare and economic opportunities.
- Social Well-being: Evaluating improvements in the quality of life for the community.
- Cultural Value: Capturing benefits related to identity, aesthetics, and recreation.
- Governance and Participation: Calculating the fairness and inclusivity of the planning process.

Each of these criteria is further broken down into specific, operational indicators. This Value Tree provides a transparent and holistic framework for evaluating how the alternative scenarios (Baseline, with BNG, without BNG) perform across all key objectives.

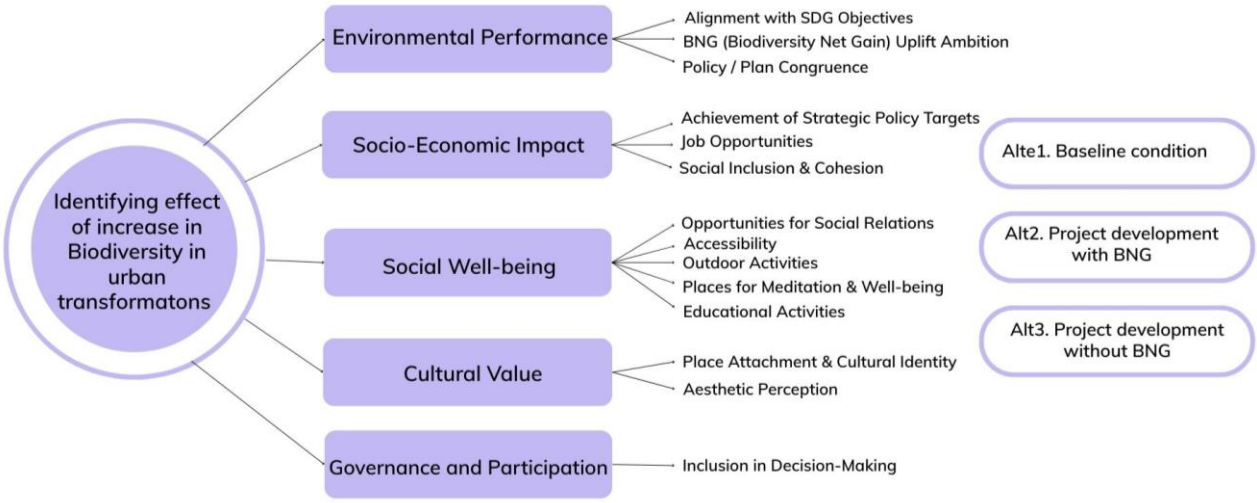


Figure 24. Value Tree for the MCDA Assessment of BNG Scenarios, Author

Performance Assessment:

The Performance Assessment phase is designed to systematically evaluate the alternative scenarios against the predefined criteria from the Value Tree. This section outlines the methodological procedure for collecting, quantifying, and preparing the performance data.

The foundation of this assessment is the Performance Matrix, which operationalizes the Value Tree by defining the specific Unit of Measure and a clear Indicator Description for each criterion. This matrix ensures that the assessment of all alternatives is consistent, transparent, and based on measurable evidence.

Criteria	Unit of Measure	Indicator Description
Alignment with SDG Objectives	Number	number of Sustainable Development Goals addressed
BNG Uplift Ambition	% Net Gain or Number	% increase in biodiversity units between baseline and post-project calculated by Statutory Biodiversity Metric or Number native plaant and species
Policy / Plan Congruence	Qualitative [1–3]	degree of project coherence with policy objectives
Project relevance scale	Qualitative [1–3]	High: national; Medium: regional; Low: local
Achievement of Strategic Policy Targets	Qualitative [1–3]	Project contribution to local/regional policy targets
Job opportunities	Number	Number of diversified job opportunities
Opportunities for social relations	Qualitative [1–3]	High: multi-functional; functional and locational diversification; medium: any of the above; low: none of the above
Accessibility	% of residents within 300 m	≥ 80 % = high access; 50–80 % = medium; < 50 % = low
Outdoor activities	Number	Number of outdoor activities such as fitness, biking, etc.
Visitors	Number/year	Estimated annual number of visitors
Places for meditation & psychophysical well-being	Number	Activities related to meditation and well-being
Educational activities	Number	Number of educational activities available
Aesthetic perception	Qualitative [1–3]	High: panoramic views, uniqueness, internal diversification
Inclusion in Decision-Making	Number	Number of different stakeholder groups engaged in formal decision-making processes
Social Inclusion and Cohesion	Number	Number of community events or initiatives promoting cohesion annually
Place Attachment and Cultural Identity	Qualitative [1–3]	High: Project enhances local identity, unique cultural value recognized; Medium: Neutral impact; Low: Detracts from identity
social attractiveness	qualitative [1–3]	High: attractive to different age groups; income; social groups medium: two of the above; low: one or none of the above

Table 18. Performance Matrix for MCDA Assessment of BNG Scenarios

The procedure for populating this matrix will be executed in two sequential stages:

Data Collection and Quantification: For each indicator in the matrix, relevant performance data will be gathered for the three alternatives (Baseline, Alt.1, Alt.2). The methodology is differentiated by data type:

For quantitative indicators (e.g., Number, Percentage), data will be sourced from project plans, design specifications, and geospatial analysis (GIS).

For qualitative indicators (scored 1-3), performances will be determined through a structured review of project documentation against the predefined descriptions in the matrix.

Normalization:

To enable aggregation within the COSIMA model, the raw performance data in the matrix will be normalized. This process will transform all values onto a common, dimensionless scale (e.g., 0 to 1), where 0 represents the worst performance and 1 the best performance among the alternatives. The resulting normalized matrix will provide the foundational input for the subsequent weighting and aggregation steps.

Criteria Weighting and MCDA Aggregation:

Following the construction of the normalized performance matrix, the next methodological step is to determine the relative importance of each criterion and synthesize this information to produce an overall performance score for each alternative. This process involves two key components:

Criteria Weighting:

The normalized performance scores alone do not reflect the fact that some criteria are more critical to the decision context than others. To address this, a set of weights must be assigned to each criterion. These weights, which sum to 1 (or 100%), represent the strategic priority of each criterion relative to the overall goal of BNG impact. The derivation of these weights is a critical and sensitive part of the MCDA process. For this study, the weights for the MCDA criteria will be established through a structured Expert Validation Process. This ensures that the weighting is robust, transparent, and grounded in informed judgement rather than arbitrary assignment.

Aggregation:

With the normalized performance scores and the validated weights defined, the overall MCDA value for each alternative will be calculated. The chosen aggregation model is the weighted sum model (WSM), in line with Multi-Attribute Value Theory (MAVT).

The central innovation of COSIMA is that the MCDA score is additive to the CBA's NPV. The $\alpha\alpha$ parameter acts as a "shadow price," integrating the strategic value assessed through

MCDA into the overall economic evaluation. This ensures that the TRR index reflects not just financial feasibility but also broader societal and environmental value.

4.4. Expert Validation Result and MCDA Criteria Weighting

The determination of the MCDA weights is a critical step that introduces subjectivity. To ensure this process is robust, transparent, and grounded in expert judgement, a dedicated validation tool was developed and deployed.

Purpose and Instrument:

A web-based tool, the BNG Indicators Expert Questionnaire (, was designed to systematically collect and quantify expert opinions. The tool presents the full set of indicators organized by stakeholder perspective (Developer, Municipality, Community) and guides experts through a four-step validation and weighting procedure.

Procedure:

Indicator Validation and Importance Rating: For each indicator, experts are required to:

Rate its Importance on a four-point Likert scale (Very High, High, Moderate, Low).

Make a binary Include/Exclude decision, providing a written justification for any exclusion.

(Optionally) propose new indicators or modifications to existing ones.

Shortlisting of Top MCDA Criteria: Experts then select a shortlist of the most critical indicators for the MCDA. To reduce cognitive burden and ensure focus, the tool guides them to select a target number of indicators (configurable between 8-15, with a default of 10). An "Auto-Suggest" function is available, which proposes a shortlist based on the pre-assigned Importance ratings, which the expert can then manually override.

Weight Elicitation: For the final shortlisted MCDA criteria, experts distribute 100 points to reflect their relative importance. The tool provides real-time feedback on the total sum and an "Auto-Normalize" function to ensure the weights total 100.

Data Export: The tool allows experts to export their complete responses, including ratings, inclusion decisions, and weights, for analysis.

4.5. Justification for the Integrated COSIMA Model in BNG Assessment

The choice of the COSIMA model, augmented with the expert validation procedure, is highly justified for evaluating BNG for several reasons:

Addresses Value Pluralism with Expert Input: BNG generates a complex mix of market and non-market values. As noted by Saarikoski et al. (2016), an integrated approach is necessary to cover

this full spectrum. The expert validation process ensures that the non-market values are weighted according to informed judgement, not arbitrary assumptions.

Aligns with Policy Objectives: BNG is a policy instrument with explicit environmental, social, and economic goals. COSIMA's multi-dimensional nature directly mirrors these policy ambitions, providing a more relevant assessment than a purely financial analysis.

Enhances Methodological Rigor and Transparency: The structured expert validation tool provides a clear, auditable trail for how MCDA weights were determined. This addresses common critiques of MCDA regarding subjectivity and arbitrariness.

Supports Stakeholder-Centric Evaluation: By basing weights on expert input, the model incorporates diverse, informed perspectives on what constitutes a "successful" BNG outcome, enhancing the practical relevance of the assessment.

Enhances Decision-Making Clarity: The final TRR index provides a clear, comparable metric for policymakers. It communicates the overall attractiveness of a project, showing how strategic benefits (validated by experts) can offset financial costs or, conversely, how a financially positive project might lack strategic value.

In conclusion, the COSIMA model, supported by the structured expert validation tool, provides a transparent framework to answer this thesis's core research questions. It enables a balanced, credible, and defensible assessment of stakeholder impacts, a comprehensive identification of benefits and externalities, and a robust basis for proposing policy optimizations for Biodiversity Net Gain.

Chapter 5: Discussion and Conclusions

5. Discussion

The aim of this thesis was to identify the impacts of the mandatory 10% BNG policy introduced in England in February 2024 and to evaluate its multi-dimensional effects across ecological, social, economic and governance domains. The primary ambition was to develop a comprehensive assessment model capable of systematically capturing and assessing the differentiated impacts of BNG implementation on key stakeholder groups.

BNG implementation has generated several concerns, including the limited ecological capacity within local authorities, uncertainties over whether on-site delivery will achieve optimal nature-recovery outcomes, and budgetary constraints that undermine effective enforcement and long-term monitoring of BNG delivery (Knight-Lenihan, 2020; DEFRA, 2023b; Natural England, 2024). From a governance perspective, local councils are expected to deliver biodiversity outcomes with constrained resources, raising risks of weakened monitoring and inconsistent application of the rules (Knight-Lenihan, 2020). At the same time, the policy is perceived as a burden on developers in the form of increased compliance costs and administrative demands (CIEEM & CIRIA, 2016; F. Baker, 2025; Wentworth, 2024). Moreover, biodiversity losses are not always compensated within the same area where communities experience those losses, which can restrict access to green spaces and lead to spatial and social inequalities (CIEEM, 2021; Taherzadeh & Howley, 2018; WHO Regional Office for Europe, 2016). These issues raise the broader question of whether the policy is effectively achieving its intended goals and how its impacts can be evaluated in a transparent and systematic way. Given the novelty of the mandatory BNG requirement and the emerging of its implementation challenges, the need for a structured, multi-dimensional evaluation framework is particularly urgent (GOV.UK, 2020; HM Treasury, 2022; Green Finance Institute, 2024).

To guide this investigation, the study was structured around three interrelated research questions:

RQ1: How can an assessment model be structured to systematically capture and compare the distinct impacts of BNG on developers, local communities and government?

RQ2: What positive and negative externalities emerge from BNG implementation, and what set of indicators and valuation methods can measure them?

RQ3: How can BNG policies be optimised to ensure biodiversity, social and institutional outcomes?

5.1. Methodological Approach

To address these questions, this study adopted a structured 3-phase methodology.

First, a stakeholder analysis was conducted to identify and justify the selection of three core stakeholder groups (Developers, Government, and Local Communities) drawing on authoritative policy frameworks including NECR502 and the Defra BNG stakeholder maps, which distinguish core, direct and indirect stakeholders and map their roles across the BNG project lifecycle. Then a dual-stream analytical phase was undertaken, aimed to identifying the full range of impacts and externalities associated with BNG implementation and selecting measurable indicators for evaluating the effects. This phase combined:

an exploratory review of policy documents, guidelines and grey literature related to BNG, habitat creation, local planning practice and environmental governance, and

a systematic scoping review of recent academic literature on ecosystem services, nature-based solutions, green and blue infrastructure and valuation frameworks, focusing on multi-criteria and economic assessment frameworks.

Together, these two streams enabled the identification of both positive and negative externalities linked to BNG from ecological, economic, social and governance dimensions and produced a comprehensive longlist of potential indicators representing these impacts. This longlist was subsequently refined to 26 indicators based on relevance, measurability. Indicators classified under the selected stakeholder groups ensuring alignment with each group's specific roles and responsibilities.

Second, the indicators were subjected to expert validation and weighting through a structured questionnaire administered to four experts representing diverse professional backgrounds (ecology, policy, urban planning and real estate). The experts first reviewed each indicator in terms of relevance, clarity and feasibility, rated its importance on Likert scales, and made include/exclude decisions with qualitative comments, they then allocated MCDA weights to a shortlisted set of criteria. This process both validated the conceptual soundness and practical measurability of the indicators and refined the indicator set into core indicators and context-dependent indicators.

Finally, the validated indicators were integrated into a customised version of the COSIMA framework, combining Cost-Benefit Analysis (CBA) for monetisable impacts with Multi-Criteria Decision Analysis (MCDA) for strategic non-monetary dimensions. These were synthesised into a unified metric of the Total Rate of Return (TRR), which enables explicit comparison of alternative BNG delivery scenarios (Barfod & Salling, 2015; Oppio et al., 2024).

Evidence from the environmental evaluation literature shows that, while CBA provides essential financial rigour for policy appraisal, it tends to under-represent non-market social and ecological values and offers limited support for analysing stakeholder trade-offs (Haase et al., 2014; HM

Treasury, 2022). By contrast, MCDA is particularly effective at structuring diverse value dimensions, incorporating stakeholder judgements and handling non-monetary criteria. In line with these findings and with calls for integrated assessment frameworks in ecosystem service and nature-based solution evaluation, this study combines MCDA with CBA within the COSIMA architecture, providing a balanced, multi-method framework capable of capturing the complex, multi-stakeholder impacts of mandatory BNG implementation.

5.2. Discussion of Main Findings

RQ1: Stakeholder Impacts, Roles and the COSIMA Framework

The final selection of Developers, Government and Local Communities as the three core stakeholder groups is a deliberate analytical choice grounded in both policy evidence and implementation practice. Based on the NECR502 typology and the Defra BNG & ENG stakeholder map, these actors emerged as the decisive axis of BNG delivery: developers as those who implement and finance interventions, local authorities as regulators and guarantors of public value, and communities as the main beneficiaries or those exposed to potential risks and distributional inequities. This structure provides the backbone for the COSIMA framework and ensures that the evaluation is explicitly stakeholder-centred.

From the developer perspective, the results confirm that BNG is primarily experienced as a cost and feasibility challenge. Core indicators such as on-site delivery cost and 30-year maintenance (B1, B5) were consistently rated High or Very High by all experts, while Policy/Plan Congruence and BNG Uplift Ambition (B8, B9) emerged as the most important strategic MCDA criteria. Together, these indicators show that developers are concerned both with the proportionality and predictability of costs and with the clarity and stability of local policy expectations.

For government, particularly Local Planning Authorities, the framework highlights the dual role of regulation and public value creation. Indicators such as urban flood risk mitigation and carbon sequestration (C1, C2) capture the contribution of BNG to climate resilience, while Achievement of Strategic Policy Targets and Ecosystem Services Provided (C3, C5) reflect the expectation that BNG delivers on wider environmental and policy commitments. Expert weights assigned to these criteria underline that municipal actors are seen as pivotal in transforming the statutory 10% requirement into meaningful, multi-functional nature recovery outcomes, despite well-documented capacity constraints.

Local communities are represented through indicators that capture lived experience and distributional equity. Access to green space within 300 m (D4) received some of the highest importance ratings and MCDA weights in the entire framework, and was repeatedly linked in expert comments to health and well-being. Inclusion in decision-making and social cohesion (D5,

D6) further emphasise that, from a community perspective, the quality of participation and the social functions of new or enhanced green spaces are central to how BNG is perceived and valued. This is consistent with wider evidence that meaningful community involvement in planning processes reduces the risk of unequal access to green space and helps to mitigate environmental and social inequalities (WHO Regional Office for Europe, 2016; Taherzadeh & Howley, 2018).

In combination, these findings show that structuring COSIMA by stakeholder group provides a coherent way to capture and compare the distinct impacts of BNG across implementation, regulation and lived experience. Rather than collapsing everything into a single ecological or monetary metric, the model makes the distribution of costs, benefits and risks across Developers, Government and Local Communities analytically visible, directly answering research question 1.

RQ2: Benefits, Externalities and Indicators

The dual-stream literature review revealed a clear imbalance in existing evaluation approaches for nature-based and BNG-related interventions. Environmental and ecosystem-service indicators, particularly biodiversity, carbon sequestration, urban cooling and flood-risk mitigation, dominate academic studies, supported by well-established biophysical models and valuation tools. In contrast, social and governance indicators such as participation, equity, cohesion or institutional capacity appear far less frequently, reflecting earlier findings that ecosystem service assessments often neglect stakeholder perspectives and trade-off analysis. These patterns highlight why BNG requires an explicitly multi-dimensional framework.

The resulting indicator set was therefore designed to be both comprehensive and practical for ex-ante appraisal. Indicators were selected based on their measurability before implementation, conceptual distinctiveness and avoidance of double-counting. Broader constructs (e.g., well-being) were disaggregated into specific, measurable drivers such as access to green space, recreation and inclusion, while overlapping hydrological indicators were merged into a single flooding/stormwater function. Minor adjustments ensured transferability beyond the UK context, such as reframing the statutory 10% requirement as a more general measure of BNG uplift ambition for jurisdictions without mandatory targets.

Expert validation further refined this set, indicating strong consensus around certain core impacts. On the cost and feasibility side, developers consistently prioritized the financial burdens associated with on-site delivery and long-term maintenance. Government experts emphasised climate and resilience related benefits, particularly flood mitigation and carbon sequestration. From a community perspective, access to green space and well-being benefits such as cooling and recreation were identified as central outcomes. More context-dependent indicators including credit prices, registration fees and property value uplift, showed greater variability and were therefore classified as scenario-specific.

By combining Likert importance ratings with MCDA weights, indicators were organised into three tiers of core indicators, required for all COSIMA applications because they reflect consistently important impacts across stakeholders and context-dependent indicators, which gain relevance in specific delivery pathways (e.g., credit markets or particular housing contexts), and optional or merged indicators, where underlying functions are already captured elsewhere in the framework. This tiered structure ensures that COSIMA remains both systematic and adaptable, directly addressing the diverse benefits and externalities identified under research question 2.

RQ3: Policy Optimisation and COSIMA's Added Value

The COSIMA framework addresses research question 3 by providing a structured way to combine economic feasibility with strategic, non-monetary priorities in BNG appraisal. At its core is the Total Rate of Return (TRR), which integrates the net present value of monetised costs and benefits (CBA) with a weighted MCDA score representing environmental, social and governance criteria. Adapted from Barfod and Salling's transport assessment work and more recent ecosystem service applications (Barfod & Salling, 2015; Oppio et al., 2024). TRR expresses the overall value of each alternative per unit of cost, allowing comparison between scenarios that generate different mixes of monetary and non-monetary impacts. The trade-off parameter α modulates the influence of the MCDA component, enabling sensitivity analysis along a spectrum from pure CBA to fully integrated multi-criteria assessment.

The expert-derived weights provide important insights into how BNG policy optimisation should be approached from each stakeholder's perspective. For developers, while direct financial burdens remain central in the CBA layer, the high weights assigned to Policy/Plan Congruence (B9) and BNG Uplift Ambition (B8) indicate that regulatory clarity, alignment with local planning objectives and the possibility of bundling BNG with other design goals are as important as nominal cost levels. For government, the concentration of weights on Achievement of Strategic Policy Targets (C3) and Ecosystem Services Provided (C5) signals that BNG is viewed as a tool for delivering broader environmental commitments and multi-functional nature recovery, rather than a narrow metric exercise. From the community perspective, Access to Green Space within 300 m (D4), together with Inclusion in Decision-Making (D5) and Social Cohesion (D6), forms the core of perceived value, underlining that physical accessibility and procedural fairness are non-negotiable dimensions of successful BNG implementation.

Taken together, these patterns show how COSIMA can support policy optimisation in practice. By modelling multiple delivery pathways (e.g. on-site enhancement, off-site habitat banks, statutory credits) and expressing their performance through TRR, the framework enables transparent ex-ante comparison of options even when some impacts cannot be monetised. The stakeholder-specific indicator structure makes the distributional consequences of BNG choices

explicit. For example, if local authorities receive adequate resources to strengthen ecological capacity and support meaningful community engagement, they are better able to involve residents in decision-making and ensure that BNG interventions improve equitable access to green space rather than reinforcing existing inequalities. COSIMA does not resolve these trade-offs automatically, but makes them visible and quantifiable, providing a structured basis for negotiation between LPAs, developers and communities.

The flexibility of the α parameter also supports scenario testing and sensitivity analysis, allowing policymakers to explore how different emphases would change the ranking of BNG delivery options. This approach is consistent with the Green Book's recommendation to complement economic appraisal with structured multi-criteria analysis for complex, multi-objective interventions and offers a concrete way to operationalise these principles for BNG (HM Treasury, 2022). The importance of such a structured evaluation framework is also underscored by the UK Green Book, which requires major policies and programmes to undergo a Post-Implementation Review within 3–5 years of enactment, in order to assess their continuing relevance, effectiveness and proportionality (GOV.UK, 2020; HM Treasury, 2022). In this perspective, the COSIMA model and its validated indicator set can be seen as a preparatory tool for future BNG reviews, providing a ready-made structure for systematically assessing whether mandatory BNG delivers its intended biodiversity, climate and social outcomes and how costs and benefits have been distributed across stakeholder groups.

5.3. Contribution to Theory and Methodology

5.3.1 Positioning Within Environmental Policy Evaluation Literature

This thesis contributes to three main strands of literature: biodiversity offset and compensation policies, ecosystem services and nature-based solutions valuation, and integrated assessment methodologies.

In the BNG field, most work to date has focused on ecological and technical aspects, the design of the Statutory Biodiversity Metric, habitat classification systems, risk multipliers and the relative merits of on-site versus off-site delivery (e.g. Bull et al., 2013; Baker, 2025). While these debates are essential, they tend to downplay the distributional and governance dimensions of BNG, such as who bears the costs, who receives the benefits and how institutional capacity affects implementation. By structuring the whole assessment framework around three stakeholder perspectives, developers, government and local communities, and by explicitly analysing how costs, benefits and risks are distributed among them, this thesis shifts attention from a narrow focus on biodiversity units towards a multi-stakeholder, multi-dimensional view of policy performance.

Across the ecosystem services and NbS literature, evaluation has tended to rely mainly on monetary and biophysical tools, with limited integration of methods and little systematic attention to equity and governance. In response, many authors call for pluralistic approaches that combine economic appraisal with multi-criteria and participatory techniques. The scoping review in this thesis confirms that single-method assessments still dominate and that social and institutional dimensions are often weakly represented. By implementing an integrated CBA–MCDA framework through a customised COSIMA model, built on a validated set of 26 indicators and expert-derived weights, the thesis offers a concrete example of how such plural approaches can be operationalised for mandatory BNG.

5.3.2 Methodological Innovation

Methodologically, the work extends CBA–MCDA hybrid frameworks by addressing the limitations of both pure CBA (strong on monetary rigour but weak on non-market values) and pure MCDA (inclusive of qualitative criteria but often detached from budget realities). Building on earlier COSIMA applications, the thesis introduces several innovations.

Dual-stream literature review: combining an exploratory review of policy and grey literature with a systematic scoping review of academic studies was used to construct an initial longlist of indicators, ensuring that both practice-based and research-based perspectives on BNG, ES and NbS were captured.

Stakeholder-specific indicator structure: organiseing criteria by developers, government and communities, keeping distributional effects visible throughout the analysis.

Cross-analysis validation method: integrating quantitative evidence (Likert importance scores and MCDA weights) with qualitative expert comments to classify indicators as core, context-dependent or optional, and to refine the indicator set based on both statistical patterns and professional judgement. Application of TRR to BNG delivery scenarios: providing a single “value per unit cost” metric to compare different mixes of on-site, off-site and credit-based provision within the COSIMA architecture.

Explicit ex-ante orientation: ensureing that all indicators are defined so they can be populated before implementation using benefit transfers, cost data, design-based scoring and GIS analysis. Together, these features show how integrated CBA–MCDA frameworks can be adapted to complex regulatory instruments such as BNG, where ecological, social, economic and institutional dimensions are closely interlinked.

5.4. Methodological Reflections and Limitations

5.4.1. Expert Panel Composition and Potential Biases

The expert validation relied on a panel of four individuals representing diverse professional backgrounds: real estate appraisal, BNG ecology and policy, urban planning and environmental planning practice. This composition ensured coverage of the main stakeholder perspectives and methodological domains relevant to the framework, including economic valuation, ecological assessment, spatial planning and local government implementation.

The geographic composition of the panel two UK-based experts familiar with England's mandatory BNG and two Italian-based experts working within European planning systems—may nevertheless have shaped the results in specific ways. For instance, the stronger emphasis on ecosystem services and strategic policy alignment may reflect the Italian experts' experience with comprehensive planning frameworks, while the UK experts' familiarity with the administrative machinery of BNG may have influenced the attention given to institutional capacity and stakeholder management.

In addition, several indicators were proposed by individual experts, meaning that non-proposing experts assigned zero weights to those criteria. This mechanically increases variance and makes it more difficult to distinguish between genuine differences in perceived importance and simple lack of familiarity with a proposed indicator. A larger, more diverse panel and an iterative process (e.g. a Delphi approach) would help to reduce these issues and improve convergence. Within these constraints, however, the current panel still provides a credible and relevant basis for the initial validation of the framework.

5.4.2 Absence of Full Empirical Application

A key limitation is that COSIMA has been developed and conceptually validated, but has not yet been fully applied to a real BNG project under actual data and time constraints. The framework is implementation-ready, all indicators have defined units, data sources and measurement procedures, but it remains untested in practice. As a result, the extent to which COSIMA can accurately support judgments about the relative "success" of different BNG options in terms of biodiversity outcomes, community benefits and long-term management performance remains uncertain.

5.5. Future Research Directions

5.5.1 Empirical Pilot Applications

A first priority is to apply COSIMA to real BNG projects, computing full CBA–MCDA TRR values for alternative scenarios under realistic data and time constraints. Suitable test could be UK BNG projects where post-implementation monitoring data are available, and voluntary biodiversity enhancement schemes in Italy or other European contexts without mandatory 10% targets.

5.5.2 Expanded and Diversified Expert and Stakeholder Input

Future research should include further validation rounds with larger and more diverse groups of experts and stakeholders. This would allow testing the stability of weights across professional communities (e.g.

ecologists, economists, planners, community representatives) and across jurisdictions implementing BNG-like policies.

5.7 Synthesis and Conclusion

This thesis set out to understand how England's mandatory 10% Biodiversity Net Gain (BNG) policy affects key actors and how its outcomes can be assessed in a way that goes beyond ecological metrics alone. By structuring the analysis around three core stakeholder groups—developers, government and local communities—and by adapting the COSIMA framework to integrate Cost–Benefit Analysis (CBA), Multi-Criteria Decision Analysis (MCDA) and a Total Rate of Return (TRR) index, the research has shown that BNG is best understood as a multi-dimensional, multi-stakeholder policy instrument rather than a purely technical requirement to achieve a fixed uplift in biodiversity units.

Taken together, the findings demonstrate that each stakeholder group experiences BNG through a distinct combination of costs, benefits and risks. For developers, BNG primarily appears as a financial and regulatory obligation, shaped by implementation costs, policy congruence and uplift ambition. For government, it represents both a governance challenge and an opportunity to advance wider ecosystem-service and climate objectives. For local communities, BNG is materialised in access to green spaces, health and well-being outcomes, and the quality of participation and inclusion in decision-making. The expert-validated indicator set, organised by stakeholder domain and refined into core and context-dependent elements, provides a practical basis for capturing these differentiated experiences in a consistent and transparent way.

By tailoring COSIMA and the TRR index to the BNG context, the thesis also proposes a concrete route for integrating monetised and non-monetised impacts within a single evaluative structure. The explicit trade-off parameter allows decision-makers to explore how different emphases on economic efficiency, ecosystem services and social equity would alter the ranking of alternative delivery options and the distribution of gains and burdens. In this sense, the work responds to calls for plural, integrated assessment approaches in environmental policy evaluation and offers an operational framework that can support ex-ante appraisal of BNG scenarios and, in the longer term, inform post-implementation review.

At the same time, the chapter has acknowledged that the framework is at an early stage. The small, though diverse, expert panel and the absence of full empirical application mean that COSIMA should currently be regarded as a conceptually robust and implementation-ready model that still requires further testing and refinement. Future research applying the framework to real projects, expanding stakeholder participation and deepening integration with spatial and planning tools will be essential to consolidate its validity and usefulness.

Overall, the thesis contributes an initial but significant step towards a more comprehensive, stakeholder-centred evaluation of Biodiversity Net Gain. It argues that credible assessment of BNG must address ecological effectiveness, economic feasibility, institutional capacity and social equity simultaneously, and must make the resulting trade-offs explicit. While no analytical framework can substitute for political judgement, COSIMA provides a structured basis for more informed, transparent and equitable decisions about how BNG is designed and implemented, and about how the benefits of nature recovery are shared across people and places.

چه خوش گفت فردوسی پاک زاد که رحمت بر آن تربت پاک باد

میازار موری که دانه‌کش است که جان دارد و جان شیرین خوش است

سیاه اندرون باشد و سنگدل که خواهد که موری شود تنگدل

سعدی

I would like to close by recalling a short poem from the rich literary tradition of my home country, Iran, which reflects many of the ethical ideas discussed in this thesis. Classical Persian poetry formed an important part of our moral education at school, and one of the verses that many children learn in elementary school is traditionally attributed to Ferdowsi (c. 940–1020 CE), with the closing line commonly associated with Saadi (c. 1210–1291 CE). In our textbooks, these lines were presented together as a single moral teaching that emphasises compassion towards even the smallest living beings. The combined verse can be translated as follows (author's translation):

Do not harm even an ant that carries its grain;
It is alive too, and life is sweet to every living being.
Only a dark-hearted and stone-hearted person
would wish even an ant to suffer.

For me, this poem encapsulates an early lesson about respect for nature and for all forms of life, not only those that appear important or useful to humans. It conveys a sense of moral responsibility and fairness that is closely related to contemporary ideas of environmental justice, the notion that harms and benefits arising from human actions should not be borne disproportionately by the most vulnerable beings and places, whether human or non-human. In this sense, the poem resonates with the ethical foundations of Biodiversity Net Gain, which seeks not only to avoid net losses of biodiversity, but also to address who and what is made to bear the ecological costs of development and who benefits from nature recovery. By ending with this reference, I also wish to highlight that the moral concerns underpinning BNG and wider debates on environmental justice are not exclusively Western or recent. Similar values have long been present in other cultural and literary traditions, including classical Persian literature, which has shaped how I think about nature and why I was motivated to work on this topic.

Bibliography

Baker, F. (2025). The impact of the biodiversity net gain requirement on the cost management of projects. *Proceedings of the Institution of Civil Engineers: Civil Engineering*, *178*(5), 21–31. https://doi.org/10.1680/jcien.24.01002

Baker, J., Hoskin, R., & Butterworth, T. (2019). *Biodiversity Net Gain. Good practice principles for development*.

Barfod, M. B., & Salling, K. B. (2015). A new composite decision support framework for strategic and sustainable transport appraisals. *Transportation Research Part A: Policy and Practice*, *72*, 1–15. https://doi.org/10.1016/j.tra.2014.12.001

BBOP. (2013). To No Net Loss and Beyond: An Overview of the Business and Biodiversity Offsets Programme (BBOP). *Washington, D.C.*, 20.

Bennett, G., Gallant, M., Author, C., & Ten Kate, K. (2017). *State of Biodiversity Mitigation 2017: Markets and Compensation for Global Infrastructure Development*. 92. https://www.forest-trends.org/publications/state-biodiversity-mitigation-2017/

Bull, J. W., Suttle, K. B., Gordon, A., Singh, N. J., & Milner-Gulland, E. J. (2013). Biodiversity offsets in theory and practice. *Oryx*, *47*(3), 369–380. https://doi.org/10.1017/S003060531200172X

Business and Biodiversity Offsets Programme. (2012). *Guidance Notes to the Standard on Biodiversity Offsets*. http://bbop.forest-trends.org/guidelines/Standard_Guidance_Notes.pdf

Cai, Y., Zhao, M., Shi, Y., & Khan, I. (2020). Assessing restoration benefit of grassland ecosystem incorporating preference heterogeneity empirical data from Inner Mongolia Autonomous Region. *Ecological Indicators*, *117*(November 2019), 106705. https://doi.org/10.1016/j.ecolind.2020.106705

CBD. (1992). Convention on biological diversity. *Estudos Avançados*, *6*(15), 193–233. https://doi.org/10.1590/s0103-40141992000200015

CIEEM, CIRIA, and I. (2016). (2016). *Biodiversity net gain*. GOV.UK. https://www.gov.uk/guidance/biodiversity-net-gain

CIEEM. (n.d.). *Biodiversity Net Gain and People's Wellbeing*. https://cieem.net/i-am/biodiversity-enhancement-approaches/biodiversity-net-gain-and-peoples-wellbeing/

CIEEM. (2021). *Biodiversity Net Gain and People's Wellbeing*. *October*, 1–16.

DEFRA. (2021). *Local Nature Recovery Strategies*. DEFRA. https://consult.defra.gov.uk/land-use/local-nature-recovery-strategies/

DEFRA. (2022). *Consultation on Biodiversity Net Gain Regulations and Implementation*. *January*, 1–109.

DEFRA. (2023a). *Biodiversity net gain*. GOV.UK. https://www.gov.uk/government/collections/biodiversity-net-

gain?utm_source=chatgpt.com

DEFRA. (2023b). *Local nature recovery strategies*. GOV.UK. https://www.gov.uk/government/publications/local-nature-recovery-strategies/local-nature-recovery-strategies?utm_source=chatgpt.com

DEFRA. (2023c). *Understanding biodiversity net gain*. GOV.UK. https://www.gov.uk/guidance/understanding-biodiversity-net-gain?utm_source=chatgpt.com

Department of Economic and Social Affairs. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. United Nation. https://sdgs.un.org/2030agenda?utm_source

Droste, N., Alkan Olsson, J., Hanson, H., Knaggård, Å., Lima, G., Lundmark, L., Thoni, T., & Zelli, F. (2022). A global overview of biodiversity offsetting governance. *Journal of Environmental Management*, *316*(February), 115231. https://doi.org/10.1016/j.jenvman.2022.115231

Fraser, S., Born, K., Hobbs, M., Steele, L., & Westerman, N. (2024). Putting nature at the heart of infrastructure using biodiversity net gain - Key insights. *Proceedings of the Institution of Civil Engineers: Civil Engineering*, *177*(6), 4–14. https://doi.org/10.1680/jcien.24.00971

González-García, A., Palomo, I., Codemo, A., Rodeghiero, M., Dubo, T., Vallet, A., & Lavorel, S. (2025). Co-benefits of nature-based solutions exceed the costs of implementation. *Cell Reports Sustainability*, *2*(3). https://doi.org/10.1016/j.crsus.2025.100336

GOV UK. (2020). *Central Government Guidance on Appraisal*.

Green Finance Institute. (2024). *Revenues for Nature Guidebook Series Biodiversity Net Gain, England Revenues for Nature Project*. *October*.

Hacking, I. (2012). Scoping studies. *Representing and Intervening*, 1–18.

Hadian, S. A., Rezayatmand, R., Shaarbafchizadeh, N., Ketabi, S., & Pourghaderi, A. R. (2024). Hospital performance evaluation indicators: a scoping review. *BMC Health Services Research*, *24*(1), 1–17. https://doi.org/10.1186/s12913-024-10940-1

IUCN. (2014). Biodiversity Offsets Technical Study Paper. In *Gland, Switzerland:IUCN*. http://cmsdata.iucn.org/downloads/final_biodiversity_offsets_paper__9nov2014_1.pdf

IUCN. (2016). IUCN Policy on Biodiversity Offsets. *IUCN Policy Statement*, 1–14. https://iucn.org/sites/default/files/2022-06/iucn_biodiversity_offsets_policy_jan_29_2016_0.pdf

Knight-Lenihan, S. (2020). Achieving biodiversity net gain in a neoliberal economy: The case of England. *Ambio*, *49*(12), 2052–2060. https://doi.org/10.1007/s13280-020-01337-5

Koscikova, Z., & Krivtsov, V. (2023). Environmental and Social Benefits of Extensive Green Roofs Applied on Bus Shelters in Edinburgh. *Land*, *12*(10). https://doi.org/10.3390/land12101831

Leadley, P., Gonzalez, A., Obura, D., Krug, C. B., Londoño-Murcia, M. C., Millette, K. L., Radulovici, A., Rankovic, A., Shannon, L. J., Archer, E., Armah, F. A., Bax, N., Chaudhari, K., Costello, M. J., Dávalos, L. M., Roque, F. de O., DeClerck, F., Dee, L. E., Essl, F., … Xu, J.

(2022). Achieving global biodiversity goals by 2050 requires urgent and integrated actions. *One Earth*, *5*(6), 597–603. https://doi.org/10.1016/j.oneear.2022.05.009

Ministry of Housing, Communities and Local Government and Department for Levelling Up, H. and C. (2024). *Biodiversity net gain*. GOV.UK. https://www.gov.uk/guidance/biodiversity-net-gain?utm_

Natural England. (2024). Biodiversity Net Gain Brochure. *Ecology and Environmeent Management*, *1*(12), 15–29. https://naturalengland.blog.gov.uk/wp-content/uploads/sites/183/2022/04/BNG-Brochure_Final_Compressed-002.pdf

NECR502, N. E. C. R. (2023). *Biodiversity Net Gain (BNG) – Policy Evaluation Plan for 2023-2025*. *September 2023*.

Onsman, A., & Burke, R. (2019). Environment & Action. *Experimentation in Improvised Jazz*, 29–35. https://doi.org/10.4324/9780429455513-5

Oppio, A., Caprioli, C., Dell'Ovo, M., & Bottero, M. (2024a). Assessing Ecosystem Services through a multimethodological approach based on multicriteria analysis and cost-benefits analysis: A case study in Turin (Italy). *Journal of Cleaner Production*, *472*(August), 143472. https://doi.org/10.1016/j.jclepro.2024.143472

Oppio, A., Caprioli, C., Dell'Ovo, M., & Bottero, M. (2024b). Assessing Ecosystem Services through a multimethodological approach based on multicriteria analysis and cost-benefits analysis: A case study in Turin (Italy). *Journal of Cleaner Production*, *472*(December 2023), 143472. https://doi.org/10.1016/j.jclepro.2024.143472

Otero, I., Farrell, K. N., Haberl, H., Pueyo, S., Kallis, G., Hobson, P., Martin, J., Kehoe, L., Plutzar, C., Nielsen, J., Rodríguez-labajos, B., Schindler, S., & Essl, F. (2020). *Biodiversity policy beyond economic growth*. *January*, 1–18. https://doi.org/10.1111/conl.12713

Paez, A. (2017). Gray literature: An important resource in systematic reviews. *Journal of Evidence-Based Medicine*, *10*(3), 233–240. https://doi.org/10.1111/jebm.12266

Pilgrim, J. D., & Ekstrom, J. M. M. (2014). Technical conditions for positive outcomes from biodiversity offsets An input paper for the IUCN Technical Study Group on Biodiversity Offsets. In *Gland, Switzerland:IUCN*. https://portals.iucn.org/library/sites/library/files/documents/2014-027.pdf

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science and Policy*, *77*(July), 15–24. https://doi.org/10.1016/j.envsci.2017.07.008

Sharman, M. (2013). Biodiversity and Ecosystem Services. In *Ecosystem Services*. https://doi.org/10.1016/b978-0-12-419964-4.00007-x

Sustainable, D. of E. development and S. A. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. United Nation. https://sdgs.un.org/2030agenda

Taherzadeh, O., & Howley, P. (2018). No net loss of what, for whom?: stakeholder perspectives

to Biodiversity Offsetting in England. *Environment, Development and Sustainability*, *20*(4), 1807–1830. https://doi.org/10.1007/s10668-017-9967-z

Teotónio, I., Oliveira Cruz, C., Matos Silva, C., & Lopes, R. F. R. (2023). Bridging CBA and MCA for evaluating green infrastructure: Proposal of a new evaluation model (MAGICA). *Socio-Economic Planning Sciences*, *85*(April 2020). https://doi.org/10.1016/j.seps.2022.101446

The Nature Conservancy. (2021). *Biodiversity Net Gain in England: Developing Effective Market Mechanisms*. *October*.

UK Green Building Council. (2023). *BNG & ENG Stakeholder map*. UK Green Building Concil. https://ukgbc.org/news/ukgbcs-launches-checklists-and-stakeholder-map-to-round-off-suite-of-biodiversity-net-gain-resources/

UK Green Council Building. (2023). *CONTENTS*. *September*.

UNDP. (2016). Biodiversity and the 2030 Agenda for Sustainable Development. *Technical Note*, 1–27. https://www.cbd.int/development/doc/biodiversity-2030-agenda-technical-note-en.pdf

Viti, M., Löwe, R., Sørup, H. J. D., Rasmussen, M., Arnbjerg-Nielsen, K., & McKnight, U. S. (2022). Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategies. *Science of the Total Environment*, *841*(June). https://doi.org/10.1016/j.scitotenv.2022.156636

Webster, V., Papworth, S., Siggery, B., Thomas, R., & Waite, M. (2023). *What are the opportunities and challenges of Biodiversity Net Gain in Surrey? July*.

Wentworth, J. (2024). Biodiversity net gain Overview . *UK Parliament POST*, *September*.

WHO Regional Office for Europe. (2016). *Urban green spaces and health*. 92.

Xu, H., Cao, Y., Yu, D., Cao, M., He, Y., Gill, M., & Pereira, H. M. (2021). Ensuring effective implementation of the post-2020 global biodiversity targets. *Nature Ecology and Evolution*, *5*(4), 411–418. https://doi.org/10.1038/s41559-020-01375-y

zu Ermgassen, S. O. S. E., Baker, J., Griffiths, R. A., Strange, N., Struebig, M. J., & Bull, J. W. (2019). The ecological outcomes of biodiversity offsets under “no net loss” policies: A global review. *Conservation Letters*, *12*(6), 1–17. https://doi.org/10.1111/conl.12664

Appendixes

Appendix A: Tables and Supplementary Data

Table A.1. Comprehensive literature extraction matrix: methods, benefit dimensions and indicators in the 18 included studies, Author

Authors	Title	Year	Methodology / Assessment Approach	Indicators Used
Esther San Jose et al.	Recommendations for a successful assessment of Nature-based Solutions in an urban context	2025	Multi-criteria evaluation; KPI measurement; Eklipse; BACI; qualitative & quantitative.	Carbon removal, temperature reduction, runoff, flood exposure, water services, air quality, accessibility, recreation, pollinators, noise, mobility, energy, jobs.
Martina Viti et al.	Knowledge gaps and future research needs for assessing non-market benefits of NbS	2022	Review of Stated Preference methods (CV, CE).	Flood prevention, clean air, climate regulation, recreation, aesthetics, biodiversity, habitat quality, property values.
Zuzana Koscikova & Vladimir Krivtsov	Environmental and Social Benefits of Extensive Green Roofs Applied on Bus Shelters	2023	Literature review + CBA using B£ST.	Air pollutant removal, carbon sequestration, rainwater retention, avoided flood damage, temperature reduction, amenity & educational value.
Meng Li et al.	How do nature-based solutions contribute to biodiversity in cities?	2025	Systematic review; CIOS; comparative analysis.	Species richness, diversity, functional diversity, biomass, microclimate, flood mitigation, social cohesion.
Alessandra Oppio et al.	Assessing Ecosystem Services through a multimethodological approach	2024	CBA + MCDA using COSIMA; SimulSoil.	Carbon sequestration, pollination, habitat quality, nutrient/sediment retention, water yield, crop/timber, NPV, costs, aesthetics, jobs, SDGs.
Andrea Lucchesi et al.	Araguaia biodiversity corridor cost benefit analysis	2024	CBA + CEA with discounted cash flow.	Carbon sequestration, SCC, avoided erosion, timber revenue, NPV, IRR, job creation, tax revenue.
Yu Cai et al.	Assessing restoration benefit of grassland ecosystem	2020	Choice Experiment; Mixed Logit; LCM; WTP estimation.	Vegetation coverage, groundwater level, rare wildlife, landscape quality, WTP.
Alberto González-García et al.	Co-benefits of nature-based solutions exceed the costs	2025	InVEST, Slidefornet; CBA; ES modelling.	Cooling, heatwave days, runoff, carbon storage, landslide risk, species counts, ROI, cost-effectiveness.

Lingyu Liu et al.	Evaluation framework for multi-scale ecological infrastructure	2024	MECBs-NbS framework.	Carbon, soil/water retention, flood mitigation, climate regulation, purification, ecotourism, health, WTP.
Alistair McVittie & Michela Faccioli	Biodiversity and ecosystem services net gain assessment	2020	Defra 2012 biodiversity metrics; ESVD.	Habitat distinctiveness, condition, biodiversity units, flood mediation, pollination, climate regulation, recreation.
Weimin Zhang & Ding Xu	Benefits evaluation of ecological restoration projects	2024	CBA (DEB, TEB, AEB); GEP; SEEA-EA.	Economic income, property value, employment, air/water purification, carbon fixation, soil conservation, flood storage, recreation.
Na Wang et al.	Benefit assessment of ecological restoration in Yellow River Delta	2025	Contingent Valuation (payment card) + Heckman correction.	Water quality, carbon sequestration, erosion regulation, biodiversity maintenance.
Peng Li et al.	Carbon credit assessment for Mangrove conservation	2025	Biomass measurement; soil C; IPCC carbon modeling; biodiversity co-benefits.	Carbon stock, sequestration, carbon credits, species richness, HCV areas, habitat quality, resilience.
Jonas Josefsson et al.	Compensating for lost nature values through biodiversity offsetting	2021	Systematic review + meta-analysis (RI, BA, CI).	Abundance, richness, diversity, reproduction, biomass, water regulation, nutrient cycling, climate regulation.
Mechtilde Gorissen et al.	Habitat Banking and Its Challenges	2020	Literature review; interviews; surveys; qualitative criteria.	Habitat type, rarity, connectivity, stakeholder engagement, governance trust, cultural identity, monitoring.
Tom Wild et al.	Valuation of urban nature-based solutions in Latin American and European cities	2024	Systematic review; interviews; Eklipse/IUCN; CBA, CV, Hedonic, TCM, DCE.	Vegetation cover, air quality, CO_2 reduction, flood/UHI mitigation, soil quality, biodiversity, recreation, aesthetics, governance, inclusion, property value, WTP.
Inês Teotónio et al.	Bridging CBA and MCA for evaluating green infrastructure (MAGICA)	2023	MAGICA (CBA + AHP-MCA).	Costs, property value, attractiveness, UHI mitigation, noise, air/water quality, habitat creation, well-being, accessibility, recycled materials.
Sumonrat Chairat & Shabbir Gheewala	Conceptual quantitative assessment framework for NbS	2024	SEEA EA + LCA + S-LCA + CBA + MCDA.	Ecosystem extent, condition, ES flows/value, GWP, eutrophication, ecotoxicity, land use, toxicity, PM2.5, ozone, jobs, equity, costs, externalities.

Table A.2. Mapping and frequency of consolidated indicators across the reviewed BNG and ecosystem service studies, Author

Authors	Title	Biomass (Aboveground/Belowground)	Air Quality Regulation and Pollutant Removal	Vegetation Coverage	Flood & Erosion Risk Reduction
San Jose et al.	Recommendations for a successful assessment of Nature-based Solutions in an urban context. URBAN GreenUP project lessons learnt		✓ ✓ ✓ ✓		
Viti et al.	Knowledge gaps and future research needs for assessing the non-market benefits of Nature-Based Solutions and Nature-Based Solution-like strategie				
Koscikova & Krivtsov	Environmental and Social Benefits of Extensive Green Roofs Applied on Bus Shelters in Edinburgh		✓ ✓ ✓ ✓		
Li et al.	How do nature-based solutions contribute to biodiversity in cities?	✓	✓	✓	✓
Oppio et al.	Assessing Ecosystem Services through a multimethodological approach based on multicriteria analysis and cost-benefits analysis: A case study in Turin (Italy)				
Lucchesi et al.	Araguaia biodiversity corridor cost benefit analysis: Large scale restoration and sustainable agribusiness in Amazon and Cerrado				
Cai et al.	Assessing restoration benefit of grassland ecosystem incorporating preference heterogeneity: Empirical data from Inner Mongolia Autonomous Region			✓	
González-García et al.	Co-benefits of nature-based solutions exceed the costs of implementation		✓		
Liu et al.	Evaluation framework for multi-scale ecological infrastructure construction benefits based on nature-based solutions		✓		
McVittie & Faccioli	Biodiversity and ecosystem services net gain assessment: A comparison of metrics				
Zhang & Xu	Benefits evaluation of ecological restoration projects based on value realization of ecological products		✓		✓
Wang et al.	Benefit assessment of the ecological restoration of the Yellow River Delta coastal wetland based on improved contingent valuation method				
Li et al.	Carbon credit assessment for Mangrove conservation: A detailed study of Futian Mangrove reserve in Shenzhen	✓		✓	
Josefsson et al.	Compensating for lost nature values through biodiversity offsetting – Where is the evidence?				
Gorissen et al.	Habitat Banking and Its Challenges in a Densely Populated Country: The Case of The Netherlands				
Wild et al.	Valuation of urban nature-based solutions in Latin American and European cities	✓	✓ ✓	✓	
Teotónio et al.	Bridging CBA and MCA for evaluating green infrastructure: Proposal of a new evaluation model (MAGICA)		✓ ✓		
Chairat & Gheewala	The conceptual quantitative assessment framework for Nature-based Solutions (NbS)		✓		

✓		✓		✓				✓	✓					✓				Water Purification and Quality
	✓	✓		✓				✓	✓	✓					✓		✓✓✓	Water Retention and Regulation
✓													✓				✓	Water Use and Availability
		✓													✓			Temperature Regulation (Cooling)
					✓		✓								✓		✓✓✓	Total Carbon Sequestration
		✓							✓			✓	✓	✓				Soil Erosion Risk Reduction
														✓				Beta diversity
		✓						✓										Pollination & seed dispersal
						✓		✓✓							✓	✓		Biodiversity Net Gain (Defra Metric)
											✓							Groundwater Level (meters of rise)
		✓		✓	✓✓					✓				✓		✓		Population Trends of Species
	✓								✓					✓				Stormwater management capacity
								✓										Time to Target Condition (Defra Metric)
				✓			✓	✓	✓							✓	✓	Climate Regulation
✓✓	✓					✓	✓			✓✓			✓✓✓	✓	✓✓			Implementation, Investment, instalment
													✓					Crop Pollination
		✓											✓			✓	✓	Food / Crop Production
																✓		Distribution of habitat
✓												✓				✓	✓✓	Greenhouse gas emissions (tCO_2e)
														✓				Native species proportion
	✓	✓					✓										✓	Noise reduction
✓		✓														✓		Ecosystem condition (integrity, degradation,
																	✓	Drinking water provision

																✓		Establishment of no-visit zones
	✓	✓					✓		✓					✓		✓	✓	Flood risk reduction
		✓			✓✓										✓✓	✓✓✓✓	✓	Habitat Connectivity & Quantity
			✓		✓✓			✓✓					✓		✓	✓✓✓		Habitat Quality and Condition
																✓		Genetic diversity
✓																		Global warming potential (kg CO_2e)
											✓							Grassland Landscape
								✓										Mediation of Liquid Flows (e.g., flood risk
✓✓✓							✓✓	✓		✓✓					✓			Ecosystem Service Economic Valuation
				✓	✓									✓				Species Diversity
				✓	✓													Species Diversity: Diversity indices (e.g.,
														✓				Species abundance
														✓				Species evenness
					✓✓✓	✓			✓	✓		✓	✓		✓			Total Carbon Sequestration
													✓					Number of shrub species (including
													✓	✓		✓✓		Number of species (species richness)
										✓								Landslide probability reduction (%)
	✓																	Use of recycled materials (e.g., C&D
														✓				Indicator species diversity
					✓													Contribution to National/Global
								✓										Difficulty of Creation (Defra Metric)
		✓			✓													Disaster risk reduction and natural hazard
		✓																Energy efficiency and avoided emissions
																	✓	Energy savings from improved green
	✓																	Use of recycled materials (e.g., C&D

	✓✓	✓			✓		✓									✓		Property value growth
												✓						Soil replacement cost
													✓					Opportunities for social relations
													✓					Number of outdoor activities (e.g., fitness,
															✓			Number of visits to green space per year
															✓			Avoided healthcare costs from increased physical
		✓	✓															Place quality, sense of place, attachment, identity
										✓								Flood regulation (Population benefited
✓	✓✓	✓✓			✓				✓				✓	✓			✓	Health and well-being (mental well-being)
																✓		Presence of gates
													✓					Estimated number of visitors per year
													✓					Number of SDGs addressed
															✓		✓	Visits and Use of Green Areas
	✓	✓											✓			✓✓✓	✓✓✓	Accessibility to green space
			✓		✓													Public participation and stakeholder engagement
		✓			✓									✓				Social inclusion and cohesion
✓		✓✓			✓								✓		✓		✓	Education, Training, and Awareness
✓														✓		✓		Social justice and equity
		✓														✓✓		Stress reduction
✓		✓												✓		✓		Quality of life
	✓	✓					✓	✓								✓✓	✓	Recreation
									✓							✓		Satisfaction
	✓✓	✓											✓✓	✓		✓	✓	Aesthetic Value
														✓		✓		Sense of place
			✓															Regulatory clarity and enforcement
		✓	✓															Trust

Table A.3. Expert comments on indicators and resulting revision decisions (include/merge/context-dependent), Author

Indicator code	Overall qualitative assessment	Synthesis of expert observations and COSIMA decision	Illustrative quote (where available)
B1	Mainly positive; core cost driver	Rated High/Very High by all experts and treated as a key cost for developers, central for tracking project viability. Several comments note that on-site delivery can, in some contexts, also be understood as a qualitative benefit/criterion when it avoids more expensive or complex off-site options. In COSIMA it is kept as a core CBA cost indicator, with an explicit note that it may additionally inform qualitative assessment in certain scenarios.	"Tracking the costs associated with the on-site delivery is of very high importance to ensure this is proportionate." (K. Twynham)
B2	Mainly positive	Importance ranges from Moderate to Very High, with experts agreeing that off-site costs are fundamental to understanding developer choices between on- and off-site BNG delivery and overall project viability, particularly where site scale and constraints limit on-site options. In COSIMA it is kept as a core CBA cost indicator for off-site delivery, central to analysing trade-offs with B1.	"This will be a priority for developers influencing how and where they deliver BNG." (K. Twynham)
B3	Mixed / context-dependent	Assessed as Moderate/Low importance. Experts recognise the statutory credit price as relevant mainly as a last-resort option and as a signal that certain habitats should generally be avoided rather than routinely offset. In COSIMA the indicator is retained but explicitly flagged as a last-resort cost, with clarified interpretation to prevent treating statutory credits as a standard component of BNG delivery.	"Should be seen as a last case scenario… use this information (price) to guide decisions to avoid development on habitats which fall into this category." (K. Twynham)
B4	Mainly positive	Rated High/Moderate and treated as part of the broader off-site cost structure. Experts consider it an administrative cost affecting scheme viability but secondary to main capital and 30-year maintenance costs. In COSIMA it is kept as a complementary cost item within off-site delivery, not as a stand-alone driver, and interpreted together with B2 and B5.	"Would be included as part of costings and will have implications for the viability of sites." (K. Twynham)
B5	Strongly positive; central indicator	Consistently rated High/Very High and emphasised as essential to capture the long-term financial commitment underpinning BNG, with costs varying by context, habitat distinctiveness and integration with neighbouring sites. In COSIMA it is kept as a core CBA cost indicator and explicitly highlighted as central for representing 30-year maintenance obligations and long-term success of BNG interventions.	"Delivery of BNG is one thing, the main part of the system is to ensure appropriate maintenance is secured for the long term." (Z. Muhammad)
B6	Mixed / context-dependent	Rated from Low to High, with one expert questioning its direct impact on developers in strict BNG settings due to stacking/bundling/additionality rules, while acknowledging possible relevance within wider nature-recovery programmes. In COSIMA it is kept but clearly marked as context-specific, interpreted as more relevant to broader nature-recovery or funding landscapes than to core BNG accounting.	"Would not see this impacting developers too much… rules should prevent the use of subsidies and grants specifically for BNG projects." (K. Twynham)

B7	Mainly positive but secondary	Assigned Moderate importance. Experts view SDG alignment as useful for strategic framing and communication but generally more critical for policymakers and government than for individual developers. In COSIMA it is retained as an MCDA criterion, but framed as more salient for policy/government perspectives and not included in the core developer indicator subset.	"More likely to be important for policy makers and government." (K. Twynham)
B8	Mainly positive / exploratory	Considered Very High by one expert and Low–Moderate by others. Experts use it as an MCDA criterion to track ambition beyond the statutory 10% requirement and to explore whether and how additional uplift is delivered or traded (e.g. off-site market). In COSIMA it is kept as an MCDA criterion for ambition tracking, but treated as an exploratory rather than universal priority across all developer cases.	"Would be good to understand if developers can easily achieve more than the mandated percentage…" (K. Twynham)
B9	Strongly positive; key MCDA criterion	Rated High/Very High across experts and seen as crucial for reducing administrative burdens and enabling multiple co-benefits when BNG is aligned with other planning and environmental policies (e.g. SuDS). In COSIMA it is kept as a core MCDA criterion, positioned as a key integrative dimension linking BNG with wider planning and environmental frameworks.	"Where there is more alignment between policies… this should reduce burdens on developers allowing them to produce multiple benefits for singular actions." (K. Twynham)
C1	Strongly positive	Rated Very High/High by all experts and recognised as a core benefit of nature-based solutions and BNG, with multiple policy connections (flood risk, climate adaptation, water and surface-water management). Some thematic overlap with Nature Recovery & Access is acknowledged. In COSIMA it is kept as a core CBA benefit, interpreted in conjunction with C6 to minimise double counting.	"Multiple benefits and policy targets." (K. Twynham)
C2	Strongly positive	Rated highly by all experts and seen as a key contribution to climate-mitigation agendas. It is linked to broader policy goals and partially overlaps with other nature-recovery functions but still considered a distinct outcome. In COSIMA it is retained as a core CBA benefit, considered alongside C1 and C6 within an integrated ecosystem-services cluster.	"Multiple benefits and policy targets." (K. Twynham)
C3	Strongly positive; core MCDA criterion	Rated High/Very High and systematically selected as an MCDA criterion. It captures how BNG contributes to city-level policy targets (climate, biodiversity, health, etc.) and to the efficient use of public resources. In COSIMA it is kept as a core MCDA criterion, representing alignment with strategic policy objectives.	"Extremely important to track the achievement of strategic policy targets to ensure they are achieving what they have set out to do." (K. Twynham)
C4	Mainly positive	Given High importance. Experts highlight its role in reflecting economic co-benefits through new jobs, upskilling and sectoral growth in restoration, monitoring and planning, relevant for inclusive green growth. In COSIMA it is retained as an MCDA criterion for employment and economic co-benefits (jobs, skills and sector development).	"Upskilling, addressing resource gaps and encouraging growth within the sector." (Z. Muhammad)
C5 (ES)	Strongly positive; new indicator	Proposed by the real-estate expert to capture the full suite of tangible and intangible ecosystem services delivered to the community by BNG, and assigned the highest MCDA weight in her responses. In COSIMA it is added as a	"It takes into consideration the benefits provided to the community by biodiversity." (M. Dell'Ovo)

		municipality-level indicator, grouped within the ecosystem-services cluster and reviewed for overlap with existing benefit indicators.	
C5 (Prot.)	Strongly positive; new indicator	Introduced by the environmental planner to ensure that protection of designated sites and priority species is explicitly monitored, distinguishing these conservation outcomes from generic ES benefits. In COSIMA it is added as an MCDA criterion, complementing the broader ES indicators by focusing specifically on protected species and sites.	"Considers the importance of protecting and conserving both protected species and designated sites…" (Z. Muhammad)
C6	Strongly positive; new indicator	Added as a new benefit indicator to emphasise the role of BNG in supporting a wider, accessible green-infrastructure network for both wildlife and people, with links to flood risk, carbon and recreation. In COSIMA it is added as a CBA benefit, interpreted jointly with C1 and C2 to reflect wider nature-recovery functions and avoid double counting.	"Recognises the importance of protecting natural assets that form part of a wider network of accessible green spaces…" (Z. Muhammad)
C8	Strongly positive; new indicator	Introduced as a new MCDA criterion to capture institutional capacity within local planning systems (skills, procedures, resources) to review and enforce BNG requirements effectively. In COSIMA it is added as an MCDA criterion, representing planning-system capacity and implementation/monitoring capability.	"Ensuring the local planning system is equipped with the skills to effectively review and ensure biodiversity considerations… are appropriately applied." (Z. Muhammad)
D1	Mainly positive; partly context-specific	Rated Moderate–High. Captures economic benefits for residents through property value uplift, seen as particularly relevant to owner-occupiers, with potential to extend analysis to rental markets. In COSIMA it is kept as a CBA benefit, with accompanying text noting differing relevance in owner-occupied versus rental contexts.	"Important to those who have purchased their own homes, may be interesting to look at this angle from rented accommodation perspective." (K. Twynham)
D2	Strongly positive	Rated High/Very High by experts. Regarded as a clear climate-adaptation and health-related benefit that can be modelled using established urban-climate methods. In COSIMA it is kept as a core CBA benefit, associated with thermal comfort and climate-resilience outcomes.	"Climate change concerns." (K. Twynham)
D3	Mainly positive	Generally rated High. Captures recreational use of green spaces and associated well-being; experts note that it should be interpreted in conjunction with accessibility to avoid over-estimating benefits. In COSIMA it is kept as a CBA benefit, explicitly linked to D4 so that recreation value is assessed together with access patterns.	"Social impact – also need to take accessibility of green spaces into consideration as well." (K. Twynham)
D4	Strongly positive; core MCDA criterion	Among the highest-ranked and most heavily weighted indicators for all experts. Directly linked to health, well-being and environmental equity, and central to how communities experience BNG. In COSIMA it is retained as a core MCDA criterion, emphasised as central to equity, health and environmental justice considerations.	"Health and wellbeing benefits to communities related to proximity to green spaces – also need to acknowledge access." (K. Twynham)
D5	Strongly positive	Rated Very High by several experts and consistently selected as an MCDA criterion. Represents procedural justice and the extent to which communities can	"Bringing community and stakeholder perspectives into account in the planning

		influence BNG design and implementation. In COSIMA it is kept as a key MCDA criterion for participation and inclusion in decision-making.	and consultation process [is] of high importance." (K. Twynham)
D6	Mainly positive; moderate priority	Rated High by some experts and Moderate by others. Captures how BNG interventions support social mixing, cohesion and equity, but is not among the very top priorities. In COSIMA it is kept as a supporting MCDA criterion within the broader social well-being cluster.	–
D7	Mainly positive; more specific	Rated Very High by one expert and Moderate by others. Highlights cultural and identity dimensions of BNG, especially where interventions reinforce local character and heritage. In COSIMA it is retained as a complementary MCDA criterion focusing on cultural identity and place attachment.	–
D8	Mainly positive; moderate priority	Rated High/Moderate. Focuses on the role of green spaces as venues for informal encounters and social networks, contributing to social capital. In COSIMA it is kept as a supporting MCDA criterion on informal social relations, grouped analytically with D6 and D13.	–
D9	Mainly positive; moderate priority	Rated High/Moderate. Measures availability of spaces that support physical exercise and outdoor leisure; conceptually clear and linked to recreation and health. In COSIMA it is kept as a supporting indicator for physical activity and outdoor leisure within the social/health dimension.	–
D10	Mainly positive but secondary	Typically rated Moderate. Acknowledged as relevant for mental health and stress reduction, but more specific than broader well-being indicators. In COSIMA it is retained as a more specific well-being criterion, not part of the minimal core set but available for context-sensitive applications.	–
D11	Strongly positive	Given high importance and selected as an MCDA criterion by several experts. Reflects opportunities for environmental education, awareness and stewardship linked to BNG projects. In COSIMA it is kept as an MCDA criterion, highlighted for capturing educational and awareness-raising functions.	–
D12	Strongly positive (but with some variability)	Importance ratings range from Low to High. Considered important for visual quality and perceived attractiveness; selected and weighted by some experts, though acknowledged as subjective and context-dependent. In COSIMA it is retained as an MCDA criterion, anchoring the aesthetic and perceptual dimension of BNG outcomes.	–
D13	Mainly positive; supportive	Importance ranges from Low to High. Captures overall image, vibrancy and perceived desirability of BNG-enhanced areas; complements property value and aesthetic indicators. In COSIMA it is kept as a complementary MCDA criterion, describing overall social attractiveness and place image alongside D1 and D12.	–

Appendix B. BNG Indicators Expert Questionnaire

B.1. Purpose and General Structure

This questionnaire was designed to validate and prioritise the Biodiversity Net Gain (BNG) indicator framework and to elicit expert-based weights for the MCDA criteria. The tool is implemented as a web-based interface titled *"BNG Indicators Expert Questionnaire — Framework Validation (v5)"* and guides experts through a structured, multi-step procedure.

The questionnaire is organised into five main sections:

- Expert information
- Settings for the number of Top MCDA indicators
- Indicator rating and selection for three stakeholder perspectives (Developer, Municipality, Community)
- MCDA weighting of the shortlisted indicators (100-point allocation)
- Summary and data export

B.2. Expert Information

At the beginning of the questionnaire, experts are asked to provide basic background information:

- Your Name*
- Your Field/Expertise* (e.g. Urban Planning, Ecology, Environmental Economics)

These fields are mandatory and are stored together with all subsequent responses. A "Reset All Data" button allows the expert to clear all previously entered information and start again with the default indicator set.

B.3. Settings: Number of Top MCDA Indicators

Before rating indicators, experts configure how many indicators they wish to select as "Top MCDA":

- A slider labelled "Select how many indicators should be selected as Top MCDA", with a range from 8 to 15, and a default value of 10 indicators.
- The current selection is displayed numerically (e.g. "10 indicators").

This setting controls the target number of MCDA criteria that will be highlighted as most important in the later selection and weighting phase and is used by the Auto-Suggest function.

B.4. Instructions Shown to Experts

The questionnaire presents a short instruction block explaining the workflow:

1. Configure the number of Top MCDA indicators (8–15, default 10).
2. Review each perspective (Developer, Municipality, Community) and rate the Importance of each indicator.
3. Optionally add new indicators with justification.
4. Decide whether each indicator should be included or excluded in the framework.
5. Select Top MCDA indicators (either manually or using the Auto-Suggest function).
6. Assign MCDA weights, distributing 100 points among the selected Top MCDA indicators.
7. Review the summary and export the results (Excel or CSV).

The estimated completion time is approximately 15 minutes, and the tool automatically saves progress in the browser.

B.5. Section 1 – Developer Perspective Indicators

For the Developer perspective, the questionnaire displays a table of predefined indicators (B1–B9 and any new indicators added by the expert). Each row corresponds to one indicator and includes the following fields:

- Rank (automatically derived from importance score).
- ID (e.g. B1, B8, B9).
- Indicator Name (e.g. “Cost of BNG Delivery (On-site)”, “BNG Uplift Ambition”, “Policy / Plan Congruence”).
- Type (CBA – Cost, CBA – Benefit, or MCDA – Criterion).
- Importance (drop-down menu: Very High, High, Moderate, Low).
- Top MCDA? (checkbox, only active for MCDA – Criterion).
- Include? (checkbox indicating whether the indicator should be retained in the framework).
- Comments (free-text field to justify exclusions or provide remarks).

Experts can also add new Developer indicators via a dedicated form:

- Indicator ID
- Indicator Name
- Type (MCDA – Criterion / CBA – Cost / CBA – Benefit)
- Importance (Very High / High / Moderate / Low)
- Description (optional)
- Justification (mandatory)

New indicators are then added to the table and marked as “ADDED BY EXPERT” in the comments.

B.6. Section 2 – Municipality Perspective Indicators

The same structure is repeated for the Municipality perspective. Indicators include, among others:

C1 – Urban Flood Risk Mitigation (CBA – Benefit)

C2 – Carbon Sequestration (CBA – Benefit)

C3 – Achievement of Strategic Policy Targets (MCDA – Criterion)

C4 – Job Opportunities (MCDA – Criterion)

Each indicator is rated on Importance, can be marked as Include/Exclude, and, if it is an MCDA criterion, can be flagged as "Top MCDA". Experts can also propose new Municipality indicators with ID, name, type, importance, description and justification.

B.7. Section 3 – Community Perspective Indicators

For the Community perspective, the questionnaire presents the set of D-indicators, including:

D1 – Property Value Uplift Attributable to BNG (CBA – Benefit)

D2 – Urban Cooling (Heatwave Mitigation) (CBA – Benefit)

D3 – Recreation Value (CBA – Benefit)

D4 – Access to Green Space (% within 300 m) (MCDA – Criterion)

D5 – Inclusion in Decision-Making (MCDA – Criterion)

D6 – Social Inclusion and Cohesion (MCDA – Criterion)

D7 – Place Attachment and Cultural Identity (MCDA – Criterion)

D8 – Opportunities for Social Relations (MCDA – Criterion)

D9 – Outdoor Activities (MCDA – Criterion)

D10 – Places for Meditation & Psychophysical Well-being (MCDA – Criterion)

D11 – Educational Activities (MCDA – Criterion)

D12 – Aesthetic Perception (MCDA – Criterion)

D13 – Social Attractiveness (MCDA – Criterion)

The same fields are available as for the other perspectives (Importance, Top MCDA, Include?, Comments), and experts can add new community indicators if needed.

B.8. Auto-Suggest Function for Top MCDA Indicators

The interface includes an “Auto-Suggest” button and a fixed counter showing:

“Top MCDA Selected: X / N (across all perspectives)”

When used, Auto-Suggest:

- Ranks all MCDA-type indicators across perspectives according to their Importance rating (Very High–Low converted to scores).
- Automatically marks the top N indicators (based on the expert’s setting, e.g. 10) as Top MCDA, labelling them as *Auto* in the interface.

Experts can then modify these suggestions manually.

B.9. Section 4 – MCDA Weighting (100-Point Allocation)

In the MCDA Weighting tab, only the indicators that have been marked as Top MCDA are shown in a separate table. For each of these indicators, the expert is asked to assign a weight (in %), such that the sum of all weights equals 100.

The table includes:

- Rank (based on importance)
- Indicator ID
- Indicator Name
- Perspective (Developer / Municipality / Community)
- Importance rating
- Selection type (Auto / Manual)
- Weight (%) (numeric input)

A progress bar and status message indicate whether the total is below, equal to, or above 100%, and an “Auto-Normalize to 100” button rescales entered weights so that they sum to exactly 100%.

B.10. Section 5 – Summary and Export

The Summary & Export tab provides a compact overview:

- Expert name and field
- Configuration (target number of Top MCDA indicators, number auto-selected vs manually selected)
- Basic counts by perspective (total indicators, included, excluded, Top MCDA)
- Total MCDA weight currently assigned

Experts can then export their full responses via two buttons:

Export to Excel – generates an .xlsx file with:

- All indicators (sheet All_Indicators),
- Perspective-specific sheets (Developer, Municipality, Community),
- A sheet with the Top N MCDA indicators.

Export to CSV – exports all indicators in CSV format.

These exports were used as the primary data source for the quantitative analysis reported in Chapter 4.