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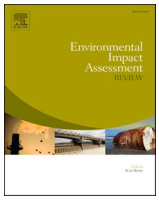

Beyond compliance: Enhancing biodiversity through transformative mitigation strategies in spatial planning related SEAs and EIAs

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ABSTRACT

The global biodiversity crisis underscores the need for transformative change in how development impacts are managed, and biodiversity is preserved. This study explores the integration of Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) within spatial planning and infrastructure projects, emphasizing their evolving role in promoting both mitigation and enhancement of impacts. Traditionally, SEAs and EIAs have focused on minimizing negative impacts through the mitigation hierarchy; however, this research advocates for a broader, proactive application that includes enhancement measures to achieve net-positive biodiversity impacts. Using a collection of 200 SEA and EIA reports from Denmark, Spain, Portugal, and Germany, analyzed within the BioValue research project, this study examines how these assessments apply the mitigation and enhancement hierarchy to promote positive outcomes. The findings reveal significant variability in the practical application of SEAs and EIAs, highlighting both strengths and gaps in integrating enhancement measures. By focusing on enhancement as a formal requirement and strengthening the 'avoidance' step in the mitigation hierarchy, this paper argues that SEA and EIA can transition from reactive assessments to proactive instruments in environmental governance and add value to spatial planning developments. The study concludes with recommendations for embedding enhancement into regulatory frameworks, encouraging a shift towards transformative environmental assessment practice.

1. Introduction: The mitigation hierarchy and the call for transformative change

The mitigation hierarchy, which includes avoidance, minimization, restoration, and offsetting, originated as part of administrative rationalism in the 1960s in response to radical environmental discourses that challenged the prevailing growth paradigm and called for limits on economic development and pollution (Damiens et al., 2021). While it is often discussed in the context of biodiversity, the principles of the mitigation hierarchy apply broadly to all environmental impacts. Offsetting, introduced as a regulatory tool, addresses residual impacts when avoidance and minimization prove insufficient (Damiens et al., 2021). As noted by Arlidge et al. (2018), the mitigation hierarchy offers "flexibility to address a variety of anthropogenic impacts on biodiversity, across different sectors and scales" (p. 337). Flexibility also extends beyond biodiversity and is supported by regulatory and financial instruments that require its application. This adaptability allowed the mitigation hierarchy to become a central approach in aligning conservation efforts with sustainable development goals (Arlidge et al., 2018).

Over time, the mitigation hierarchy has evolved and been widely embedded into modern governance frameworks, notably through the EU's policy instruments, the Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) Directives. These Directives apply the key principles of avoid, minimize, and off-set to guide projects and plans with the potential for significant impact, aligning them with sustainable development objectives.

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1.1. Biodiversity mitigation in a broader institutional context

In a European context, other directives contribute to governing biodiversity, namely the Bird and Habitat (H/B) Directives, which under Article 6 mandate stricter protective measures than SEA and EIA, particularly for Nature 2000 sites. These directives require not only rigorous screening for potential impacts on protected habitats and species but also that they meet stringent criteria before approval. Specifically, any plan or project that may affect a Nature 2000 site must undergo an Appropriate Assessment (AA) to ensure that it will not adversely affect the integrity of the site. The AA must demonstrate that there are no alternative solutions and that necessary compensation measures are in place to protect the overall coherence of Natura 2000, and compensation is seen as the last resort (McGillivray, 2012; González et al., 2013). The sequential approach contrasts with the more flexible mitigation hierarchy in EIA and SEA, where compensation can be considered alongside avoidance and minimization (Larsen et al., 2024; González et al., 2013). Furthermore, for EIA and SEA, authorities must consider the impacts, while the outcome of an AA is legally binding and conditions the final decisions of the authorities (Pouikli, 2025; McGillivray, 2012). In their work on improving biodiversity impact assessment practices, González et al. (2013) also emphasize the integration of assessment procedures as a critical step towards enhancing the effectiveness and quality of biodiversity assessments. In this regard, the EU H/B Directives, as well as the practice of AA, influence the regulatory landscape of SEA and EIA.

In this paper we draw focus to the distinct roles played by the EIA and SEA frameworks within environmental governance. Our analysis is rooted in the broader applicability of SEA and EIA across various types of plans and projects that go beyond the strictly protected areas under Natura 2000. SEA and EIA cover a wide range of environmental considerations, including all types of nature and biodiversity, not solely those strictly protected by the H/B Directives. Additionally, while the H/B Directives play a crucial role in specific ecological and conservation contexts, our goal in this study was to explore the use of the mitigation hierarchy in impact assessment practice, given its current flexibility within EIA and SEA frameworks.

1.2. Enhancement in SEA and EIA for transformative change

Embedded within the European EIA and SEA Directives, the mitigation hierarchy aligns closely with several core environmental principles: the precautionary principle, the polluter-pays principle, and the prevention principle (Vomácka, 2024). The precautionary principle emphasizes caution in decision-making when there is scientific uncertainty about potential impacts, which aligns closely with the principle within the mitigation hierarchy that avoiding and minimizing impacts before they occur should be prioritized higher than off-setting and repairing impacts. The polluter-pays principle holds developers accountable for the potential environmental damage they cause, ensuring that they bear the costs associated with controlling and preventing it. The prevention principle aims to eliminate or significantly reduce environmental harm at its source, which, like the precautionary principle, also aligns with the mitigation hierarchy's initial steps – avoidance and minimization. This prevention principle is foundational in guiding environmental assessments (EAs) not only within Europe but also serves as a valuable model globally, influencing environmental governance in jurisdictions beyond the European context.

Despite these embedded principles, the concept of enhancement – actively improving biodiversity beyond baseline conditions – is not a formal requirement within the current European regulatory EIA and SEA frameworks. Enhancement measures, which could include habitat restoration or proactive seek biodiversity gains, remain largely voluntary. This absence reflects a regulatory gap where enhancement is seen as an additional benefit rather than a mandated component of planning and project design.

This limitation contrasts with the evolving discourse around transformative change, reflected in the increased calls for societal transformation, for example, with the international urging of world leaders in 2015 to set up a priority agenda to transform our world (United Nations General Assembly, 2015), resulting in the 2030 Agenda for Sustainable Development (SDGs). More and more examples of these calls for social transformations are visible globally (e.g., Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019;2024) and locally, as emphasized by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019) and further supported by the literature on sustainability transformations (e.g., O'Brien, 2012; Patterson et al., 2017; Linnér and Wibeck, 2019; Scoones et al., 2020; Loorbach et al., 2017; Wittmer et al., 2021). IPBES calls for a shift from merely managing impacts to transformative change, which requires addressing both direct drivers of biodiversity loss, such as habitat destruction and pollution or land use change, and indirect drivers and their underlying causes. The latter include unsustainable economic systems and governance models that prioritize short-term growth, individual and material gains over long-term ecological health – a disconnection from and domination over nature and people and the concentration of power and wealth (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019). Diaz et al. (2019) also argue that achieving transformative change calls for a fundamental reorganization across technological, economic, and social factors, including paradigms, goals, and values. Arguing also for a paradigm shift, Nykiel and Morrison-Saunders (2023) advocate for 'letting nature speak' and including nature as a stakeholder in impact assessment which draws similarities to the emerging discussions of 'rights of nature' (UN Environment Programme, 2022; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019), suggesting that nature should have inherent rights and legal protection.

Merely compensating for biodiversity loss does not sufficiently address these underlying drivers; instead, there is a need to shift towards more proactive and transformative approaches that fundamentally rethink how human activities intersect with natural systems (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019; 2024). This includes prioritizing enhancement measures that not only mitigate impacts but avoid them, that actively restore and improve biodiversity. Socio-ecological considerations need to be integrated into the core of decision-making processes, reorienting societal developments that drives environmental degradation. One way to push this integration is by mainstreaming ecosystem services (ES) into EA, which can represent a crucial step in that direction (e.g., Geneletti, 2011). By linking impacts to the tangible benefits ecosystems provide to human well-being, EA can provide a more holistic understanding for planning and policy making of how development decisions affect biodiversity (Geneletti, 2016).

In this light, formally incorporating enhancement formally into the SEA and EIA processes frameworks, and into the mitigation hierarchy, could support transformative change. Enhancement measures can, e.g., lead to the creation of new habitats and increase the resilience of natural systems, and by actively working towards net positive outcomes, enhancement can shift environmental governance from mitigating harm to fostering biodiversity recovery and growth. In this sense, enhancement addresses root causes and aligns with the call for transformative change, where reducing impacts is shifted towards contributing positively to ecological systems.

1.3. Focus on spatial planning and infrastructure development

This research specifically examines SEAs and EIAs in spatial planning and related infrastructure development due to their substantial role in driving biodiversity loss, land-use change, and environmental degradation. Spatial planning and infrastructure projects often involve large-

scale conversion, habitat fragmentation and ecosystem disruption (Fahrig et al., 2019; Hoyos-Rojas et al., 2023; Hogue and Breon, 2022; Van de Ven et al., 2021), making them critical targets for applying the mitigation hierarchy to mitigate negative impacts and potentially enhance biodiversity.

Spatial planning fundamentally shapes land use, determining how societies organize space, develop infrastructure, and manage natural resources. As such, it influences both direct (e.g., land conversion, pollution) and indirect drivers (e.g., economic policies, urban expansion) of biodiversity loss, as highlighted by Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2019). Given that spatial planning decisions set a framework for future development, integrating robust mitigation and enhancement measures through SEA can significantly influence how impacts on biodiversity are managed from the outset (Geneletti, 2011; Partidario, 2024). Infrastructure development, including transport infrastructure and energy projects, often has substantial, cumulative, and lasting environmental impacts (Niebuhr et al., 2022; Hogue and Breon, 2022). These types of projects can trigger cascades of ecological changes, such as water flow alterations, loss of critical habitats and fragmentation, which makes the application of the mitigation hierarchy essential.

Based on this, the research question guiding this study is: *How do spatial planning-related SEAs and EIAs integrate mitigation and enhancement measures for biodiversity, particularly in light of the shift towards enhancement and transformative change in environmental governance?*

By focusing on SEAs and EIAs within spatial planning and infrastructure development, this research illustrates how these assessments can mitigate, hereunder avoid, negative biodiversity outcomes and simultaneously enhance positive outcomes, aligning with the broader call for transformative change in environmental governance. In response to e.g. the call of Nisbet and João (2022) for more empirical evidence of the use of enhancement, the research adds to existing knowledge further insights into practical application of enhancement and the mitigation hierarchy in SEA and EIA, highlighting aspects for improvement. This focus allows for a critical evaluation of current practices and identifies opportunities to embed enhancement measures, thus advancing sustainable development goals.

To this end, the study examines SEA and EIA practices in four European countries (Spain, Portugal, Germany, and Denmark), analyzing how these countries implement the mitigation hierarchy and also proactively enhance biodiversity. Drawing on perspectives from Damiens et al. (2021), who advocate a shift from off-setting as a last resort to proactive, transformative strategies, this research investigates how these trends are reflected in EA across different national contexts, identifying best practices, gaps, and opportunities for improvement.

The novel aspects of this research emphasize the integration of proactive enhancement measures within SEAs and EIAs, advocating for a shift from traditional compliance-focused approaches to actively improving biodiversity. This proactive approach formally incorporates enhancement measures into the mitigation hierarchy. This comparative analysis across four European countries identifies variability in the application of the mitigation hierarchy, proposing enhancement to regulatory frameworks to embed enhancement formally.

The article begins by unfolding the mitigation hierarchy, its application, and practical targets. Next, it details the methodologies for analyzing the current application of the mitigation hierarchy to biodiversity impacts and presents the findings. The conclusion places these findings within the broader context of transformative change, exploring how EA can evolve to address immediate and systemic drivers of biodiversity loss, as well as limitations encountered in this study.

2. Unpacking the mitigation hierarchy: Principles and contemporary applications in environmental governance

This section explores the mitigation hierarchy, its guiding principles and some key scholarly findings related to the use of the hierarchy in SEA and EIA practice. It is focused on the ongoing debate about the need to move beyond traditional mitigation towards more transformative, enhancement-focused strategies that actively restore and improve biodiversity. By unpacking the hierarchy, Section 2 identifies key themes, challenges, and opportunities associated with its implementation, which are crucial for shaping the study's analytical approach and methodology, presented in Section 3.

2.1. Mitigation hierarchy

To understand the effectiveness and intent of biodiversity measures in EIA and SEA reports, it is essential to categorize them within the established mitigation hierarchy. The mitigation hierarchy is a structured framework that prioritizes actions to address environmental impacts (see Fig. 1). This categorization helps to systematically classify the measures into five primary categories within the hierarchy.

The mitigation hierarchy emphasizes "no net loss" of e.g., biodiversity, ranging from avoiding, minimizing, repairing and off-setting negative impacts (Glasson and Therivel, 2019). This framework prioritizes avoidance, as it prevents potential harm to biodiversity before it occurs to preserve ecological integrity. If avoidance is not feasible nor possible, minimization is the next level in the hierarchy, aiming to reduce impact on biodiversity. Restoration follows as a key measure, focusing on restoring disturbed ecosystems, and is crucial for supporting ecosystem recovery. Off-setting involves creating, enhancing, or protecting equivalent biodiversity values elsewhere to compensate for unavoidable losses. Offsetting is considered the last resort, as it involves trade-offs that may not fully compensate lost biodiversity (Larsen et al., 2018; Lindenmayer et al., 2017).

Reimagining the mitigation hierarchy by placing enhancement at the top has been discussed for a long time in EIA literature (see e.g. Bond et al., 2013). However, it is only recently that more specific proposals in this regard have been made (Sinclair et al., 2022; Morrison-Saunders and Sánchez, 2024), responding to the call for a next generation impact assessment to "go beyond mitigation of adverse environmental effects to deliver net positive contributions to lasting well-being" (Sinclair et al., 2022: 3). Enhancement transcends traditional mitigation by actively improving biodiversity conditions beyond their current state. It aims to create net positive outcomes, representing the most proactive step in the hierarchy, focusing on achieving long-term ecological gains.

2.2. Application of the mitigation hierarchy

The mitigation hierarchy emphasizes avoidance as the most effective biodiversity conservation strategy, involving four main approaches: (1) action cancellation, which stops harmful activities, (2) spatial avoidance, which relocates activities to less sensitive areas, (3) temporal avoidance, which adjusts activity timing, and (4) design-based avoidance, which modifies activity design to minimize biodiversity impact (Phalan et al., 2017). These measures seek to mitigate harm but also

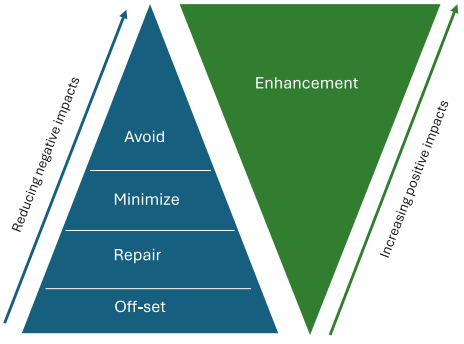

Fig. 1. The mitigation and enhancement hierarchy. (Kørnøv and Ravn Boess, 2024).

aligns conservation efforts with sustainable development goals, ensuring that biodiversity impacts are minimized from the outset.

Despite being the most desirable form of mitigation measure and often mandatory inclusion in EA processes (Pope et al., 2013; Phalan et al., 2017), avoidance measures are critically underused. For instance, only 13 % of proposed measures for marine ecosystems in France focused on avoidance (Jacob et al., 2016), and only 10 % of measures concerning biodiversity impacts from Danish linear infrastructure were avoidance-based (Larsen et al., 2015).

Offsetting measures, intended as mitigation last resort, are sometimes misused or poorly executed. These include direct offsets by developers through restoration; banking mechanisms via third parties generate offset credits through pre-emptive restoration; and offsetting funds managed by organizations (Calvet et al., 2015). Larsen et al. (2018) noted significant variability in the design and implementation, often not adhering to core mitigation principles of prevention. Cares et al. (2023) also found a preference for off-setting over avoidance or repair in Chilean EIA practices, particular in mining. This trend underscores a systemic shift towards off-setting, compromising the mitigation hierarchy's effectiveness in minimizing biodiversity impacts.

Jacob et al. (2016) identified a similar pattern where over two-thirds of cases proposing off-set measures lacked prior efforts to avoid or reduce impacts, undermining the structured approach of the mitigation hierarchy and highlighting a broader issue within environmental governance. This pattern of bypassing initial hierarchy levels calls for stricter adherence to mitigating principles to ensure biodiversity protection.

Persson et al. (2015) argue that while off-setting is both an ethical and ecological responsibility aligned with the polluter-pays principle, its premature use risks undermining the hierarchy's overall goal. For meaningful biodiversity protection, implementing rigorous avoidance and minimization strategies before considering off-sets is crucial.

2.3. The targets of mitigation and enhancement measures

Mitigation and enhancement measures aim to address and improve biodiversity, but their specific targets can vary widely, reflecting diverse conservation priorities and ecological contexts. These measures often focus on species and habitats, influenced by regulatory frameworks and conservation goals. The H/B Directives have strongly influenced this focus, emphasizing the protection of listed species and habitats. This approach has prompted a shift in EAs to prioritize ecological protection (Romao, 2014).

Research highlights a trend towards targeting listed species and habitats at the expense of broader ecological considerations. For example, Bigard et al. (2017) examined 42 EIAs for small development projects in France and found that the "main focus is on listed species and habitats with less interest in common species and habitats." (p. 41). This emphasis on protected species reflects compliance with regulatory requirements but also reveals a gap in addressing the broader ecological network. Similarly, Larsen et al. (2018) found in their study of 67 EIAs for infrastructure projects a notable shift from a broader focus on various habitat types, such as forest, lakes, streams, and meadows, to a focus on listed species, particularly bats, otters, frogs, and amphibians. This shift reflects evolving conservation priorities but also highlights a narrowing of scope that may overlook the ecological value of common habitats.

The primary concern with the approach is the underrepresentation of common habitats and species. As Bigard et al. (2017) note, "common habitats and species play a major role as part of the habitat or landscape used by listed species … and in terms of provision of ecological services" (p. 41). The limited focus on these elements in EA can undermine the broader ecological integrity of landscapes and reduce resilience of ecosystems. A challenge lies in expanding mitigation and enhancement targets to encompass a more holistic ecological perspective, addressing not just the listed species but also the common elements that underpin ecosystem health and functionality.

The effectiveness of the mitigation hierarchy is complicated by the cumulative impacts of multiple projects or actions over time and space, which can amplify biodiversity effects (Dibo et al., 2018; Thérivel et al., 2021), thus requiring an understanding going beyond assessing individual plan or project impacts.

2.4. The role of formulation of measures and implementation timing

Mitigation and enhancement measures in EIA and SEA reports range from strong, binding language to more discretionary terms.

Larsen and colleagues analyzed 1223 biodiversity impact measures in infrastructure projects EIA reports, finding 771 measures with mandatory "shall" commands, 329 with advisory "should" suggestions, and 123 with optimal "can" formulations (Larsen et al., 2015; Larsen et al., 2018). Weaker terms ("should" or "can") frequently remain unimplemented or are deferred to future decisions, reducing their impact and effectiveness (Kørnøv, 2014; Larsen et al., 2018). In contrast, strongly worded, legally binding measures are more likely to be enforced, highlighting the importance of precise, enforceable language. Jacob et al. (2016) emphasize that "Mitigation measures need to be enforced and not viewed as a series of non-binding proposals" (p. 95). This is echoed by Pindaru et al. (2023), who discuss the power of precise language in legal and policy frameworks. Weak enforcement mechanisms often contribute to the disconnect between mitigation recommendations, monitoring, and actual implementation, reducing the effectiveness of EIAs in achieving environmental goals (Nita et al., 2022).

The effectiveness of mitigation and enhancement measures depends not only on their framing but also when and where they are applied. The 'implementation length' – the duration from proposal to implementation – affects their success. Measures introduced during early design or planning phases are more likely to be implemented, while measures deferred to lower planning tiers face integration challenges if the lower levels fail to or only partially comply. Gallardo and Bond found in their Brazilian and English case studies "that tiering of biodiversity objectives does exists but is limited", highlighting the need for more explicit transfer of information from SEA to EIA (Gallardo and Bond, 2024: 289). Effective adoption of decisions from higher-tier SEA level in lower-tier processes ensures that strategic and operational mitigation aspects are consistently considered.

3. Methodology for analyzing mitigation measures for biodiversity

We have employed a two-tiered methodological approach to analyze mitigation measures within EAs. The first tier involves a comparative analysis across four European countries. Although these countries follow the same underlying regulatory framework provided by the EU SEA and EIA Directives, the study aims to identify commonalities and differences in the use of mitigation and enhancement measures across the four national contexts – Denmark, Spain, Portugal and Germany. This broad comparative framework provides insights into how each country interprets and implements the directives in practice, offering a sense of the extent to which mitigation strategies are standardized or adapted to local conditions.

The second tier of the methodology focuses on a detailed examination of Danish SEA and EIA reports. This deeper analysis allows for a nuanced exploration of specific mitigation and enhancement measures employed in Danish planning processes, categorizing them according to the mitigation hierarchy (avoid, minimize, restore, off-set, enhance). This study also investigates the formulation of these measures, assessing the language used (e.g., "must", "should", "can") and the mechanisms that ensure their implementation.

This two-tier approach enhances the robustness of the study, providing both broad, international perspectives and detailed national insights into the effectiveness of mitigation practices under the shared

regulatory framework.

Our study examines the reporting phase of measures in SEA and EIA, excluding implementation. While we analyze type, formulation, and timing, we do not assess post-reporting effectiveness. This limits our ability to capture the complexities of tiering, information transfer across planning stages, and feedback mechanisms, which are crucial for effective environmental improvement.

3.1. Selection of SEA and EIA reports

The initial analysis strategically draws from a diverse collection of SEAs and EIAs across four countries. These countries are integral components of the BioValue research project, which aims to "safeguard and enhance biodiversity through transformative spatial policymaking, planning practices and infrastructure development, upscaling opportunities for valuing biodiversity" (Partidario, 2024: 4). With these countries the analysis covers a geographical gradient within the EU (northern, central and southern Europe) – but also leverages the project team's linguistic proficiency and contextual understanding of the regional environmental policy landscape.

Denmark's 110 out of 200 reports reflects its leading role in the BioValue project's work on EA methodologies, allowing for an in-depth examination of Danish practices. The sample furthermore includes 20 reports from Spain, 41 from Portugal, and 20 from Germany, providing a comparative perspective on SEA and EIA implementation across distinct governance, policy, and regulatory contexts in Europe. The 200 reports were selected based on:

1. *Recency*: Only reports from the past five years to ensure relevance.
2. *SEA focus on spatial planning*: Reports related to land use and biodiversity on national, regional, or local levels. The reports cover comprehensive spatial plans and local-level planning.
3. *EIA focus on major land-use projects:* Reports on roads, railways, photovoltaic plants and coastal protection, chosen for their potential to significantly impact biodiversity during construction and operation due to their geographical scope and nature.

These criteria ensured that the 200 reports were highly relevant, focused, and directly related to significant biodiversity impacts. The selected reports include on-shore and off-shore projects and plans.

The initial analysis provided preliminary insight into mitigation and enhancement across the four countries, providing a comparative basis for different practices. The granularity of this analysis is on the report level, characterizing general practices rather than the individual measures.

For a more in-depth analysis that delves into further details of the individual measures, a sample of the Danish reports were selected, namely 51 of the 110 Danish reports. The 51 reports were chosen as a sample size of the 110 reports total and aimed to cover a wide range of spatial plan and project types. They covered 37 SEAs for overall spatial plans (such as municipal plans), local plans and supplements to municipal plans, as well as 14 EIAs on linear infrastructure (road development projects) and renewable energy projects requiring significant land use (solar and wind projects). The sample was selected to ensure representation from all plan and project types otherwise represented in the original 110 Danish reports. This study explored the reports in more detail, outlining how enhancement and mitigation measures are described in the reports, the recipient they aid, and how the measures are categorized according to the mitigation hierarchy. The granularity of this second analysis is on the individual mitigation measure, meaning that the results represent the total percentage of measures from the total number of measures across the 51 reports. This differs from the initial analysis across the four countries, where the focus is on the individual report and the results represent the percentage of reports from the total 200 European EA reports, rather than the individual measures themselves.

Our analysis deliberately excludes Appropriate Assessment (AA), mandated under the H/B Directives for projects and plans affecting Nature 2000 sites. This allows us to focus on the broader application and effectiveness of SEA and EIA in mitigating and enhancing biodiversity impact.

3.2. Analytical framework

Guiding questions structured the analysis of 200 reports across four countries. This broader analysis was based on a benchmark report from BioValue (Larsen et al., 2023), providing a standardized framework for assessing SEA and EIA effectiveness. While the benchmark covers a range of indicators across multiple themes, this study focuses on those related to the mitigation hierarchy and enhancement measures.

1. *How are biodiversity impacts mitigated in the EA*? exploring whether biodiversity impacts are mitigated according to the mitigation hierarchy, based on an analysis of residual impacts, or mitigated through the enhancement of biodiversity values.
2. *To what degree are biodiversity impacts mitigated in the EA*? exploring whether biodiversity impacts are mitigated so that "no net loss" or "net gain" is achieved.
3. *How are mitigation measures worded*? exploring whether a measure "can", "should" or "must" be implemented, which then influences the strength of the requirement for implementation of the measure.

Building on this broader analysis, the study conducted an in-depth examination of the Danish SEAs and EIAs, further analyzing and categorizing specific mitigation and enhancement measures. The following questions guided this detailed analysis, aiming to provide a comprehensive view of how mitigation and enhancement is applied within the Danish context and identifying best practices that could inform improvements across BioValue countries and beyond:

3.2.1. What types of mitigation and enhancement measures are used?

This question focuses on identifying the specific types of mitigation measures. Our analysis began with a set of categories derived from authors' previous research and practical engagement with SEA and EIA reports (Nielsen et al., 2023). The initial categories provided a foundational framework, and as the document analysis progressed, we employed an abductive approach to refine these categories. As such, new categories were identified, and existing ones were modified to better capture the range of measures documented in the reports. The finalized categories are:

- **Nature management/maintenance –** activities that involve ongoing management or upkeep of natural areas.
- **Rehabilitation** – measures aimed at restoring disturbed habitats to their original or improved state.
- **Compensatory nature** – actions taken to compensate for environmental losses that cannot be avoided or minimized.
- **Construction requirements** – specific conditions imposed during construction to mitigate impacts.
- **Passage/corridors and planting** – creating pathways or green corridors to facilitate wildlife movement.
- **Alternative design/technology** – using innovative designs or technologies to reduce impacts.
- **Alternative location/route** – selecting locations or routes that minimize ecological disturbance.
- **Preserving land-use purpose** – ensuring that land use remains consistent with land-use objectives.
- **Distance requirements** – implementing spatial buffers to protect sensitive areas.
- **Timing** – adjusting the timing of activities to avoid critical periods for wildlife.

- **Other measures** – additional strategies that do not fit into the abovementioned categories but contribute to biodiversity mitigation or enhancement.

3.2.2. What are the measures aimed at?

This part of the investigation focuses on identifying the purpose of the measures for biodiversity, with a focus on what these measures are designed to protect – the recipient.

An adaptive and iterative approach allowed us to remain flexible and responsive to the specific recipients and biodiversity components identified within the reports. Thereby, the analysis was not constrained by rigid classifications but was shaped by the actual recipients encountered across the various case reports. This grounded approach ensured that the categorization captured the diverse range of species and habitats that the mitigation and enhancement measures sought to protect.

This allowed for the inclusion of both explicitly identified recipients and less obvious ones that might not fit within traditional categories, enhancing comprehensiveness and nuancing understandings of the purposes these measures serve.

Identifying measures for biodiversity included a categorization that organized the recipients based on their level of legal protection and made a distinction between habitats and species. This dual categorization provides a comprehensive view of how biodiversity was addressed in the spatial-planning and infrastructure-development context.

The measures were categorized into three levels of protection, and a fourth category that encompasses general or non-specific references to habitats or species:

- **Strongly protected habitats and species** – the highest level of legal protection, primarily under EU nature directives such as the H/B Directives
- **Protected habitats and species** – protection under national law
- **Non-protected habitats and species** – not legally protected
- **General or non-specific reference** – recipients are vaguely referenced in the SEA and EIA reports, with no identification of particular species or habitats

3.2.3. Which category of measure does it belong to within the mitigation hierarchy?

The categorization is based on a detailed analysis of different types of mitigation measures outlined in the reports, which are organized according to the hierarchical structure presented in Fig. 1. This framework classifies the measures into five categories:

- **Avoidance** – designed to prevent negative biodiversity impacts from occurring in the first place.
- **Minimization** – aimed at reducing the intensity, extent or duration of impacts.
- **Repairing** – actions taken to repair ecosystems that have been degraded or disturbed by activities.
- **Off-setting** – compensatory actions taken when residual impacts cannot be fully avoided, minimized, or restored.
- **Enhancement** – improving the state of biodiversity.

The final part of the analysis focuses on the implementation of the mitigation and enhancement measures, which leads to the following questions:

3.2.4. How explicitly are the measures formulated?

This analysis is grounded in a methodological framework that examines the specificity and enforceability of measures. We utilize a linguistic analysis framework that focuses on the language used to articulate commitments to biodiversity protection within reports (see Kørnøv, 2014; and Larsen et al., 2018). This approach enables us to discern the binding nature of each measure based on its phrasing. The analysis distinguishes between four distinct formulations:

- **Mandatory formulations** – phrases such as "shall" or "must" imply legally binding requirements that must be implemented. These formulations indicate a high level of commitment to biodiversity protection, ensuring that proposed actions are compulsory within the project scope.
- **Advisory formulations** – words like "should" suggest that measures are recommended but not obligatory, allowing room for discretion. This language might reflect best practice advice rather than enforceable requirements.
- **Optional formulations** – terms such as "can", "could", or "may" denote that measures are possible but not required, offering minimal assurance that they will be carried out. These formulations tend to undermine the potential impact of the mitigation hierarchy, as they lack enforceability.
- **Expected formulations** – the term "prerequisite" indicates that a measure is expected to be implemented, suggesting an anticipated outcome without legally binding force. This type of formulation creates an intermediate level of commitment but lacks enforceability and might rely on implicit agreements or internal expectations within the planning process.

3.2.5. How is it ensured that the measure is implemented in practice?

Our methodology for assessing the implementation assurance of measures employs the concept of tiering to examine how these measures are sought operationalized across different levels of planning and project execution. Tiering facilitates a comprehensive understanding of the interconnected layers of decision making and is designed to trace and ensure the consistency of commitments across vertical (different planning levels) and horizontal (sectors) tiers (Therivel and González, 2021; Arts et al., 2011; Gallardo and Bond, 2024). The analysis considers four approaches that play a critical role in understanding tiering and how measures are carried out in practice:

- **Ensured in the plan/project** – This approach reflects that the measure is directly integrated into the plan or project. Measures that are embedded within the project design or main planning documents are generally subject to binding commitments, making their implementation mandatory. This integration can be linked to clear conditions, permits, or approvals, ensuring that the measures are actively carried out during implementation.
- **Ensured in a subsequent plan/project** – Some measures are deferred to future stages, requiring incorporation into subsequent planning processes or related projects. This approach relies on a continuation of oversight and integration across different tiers of planning and thus poses risks if subsequent plans lack the necessary enforcement mechanisms.
- **Ensured through EIA for individual facilities** – Measures may also be ensured through specific EIA processes tailored to individual facilities within a broader project, and measures are validated and enforced at a more granular level.
- **Ensured in other planning** – Measures that are ensured through other related planning frameworks, such as sectoral policies or plans, rely on broader regulatory and planning structures to drive their implementation.

4. Results

4.1. Mitigation strategies across countries

The first analysis involves a comprehensive review of 200 SEA and EIA reports from the four European countries, Denmark, Spain, Portugal, and Germany (Larsen et al., 2024). Note that each EA report can contribute to more than one indicator, meaning the percentages in the tables do not necessarily add up to 100 %. The absolute numbers of reports are included in parentheses.

4.1.1. How biodiversity impacts are mitigated

Our results provide insights into whether the biodiversity impacts are (1) mitigated using the mitigation hierarchy and thereby, a reactive response to identified impacts, (2) mitigated based on residual impact, or (3) mitigated through enhancement and thereby, a more proactive effort towards furthering and enhancing biodiversity. The results are shown in Table 1. It should be noted that each EA report can contribute to more than one of the columns in the table, meaning it can include more than one element, and some reports may not include any elements at all. Thus, the percentages in the table do not add up to 100 %. The results suggest that mitigating according to the mitigation hierarchy is most predominant. This is more the case for EIAs than SEAs in all countries but Spain. Mitigating according to residual impact is not as practiced, especially not in Portugal and Germany. Moreover, only a small number of reports in all countries exhibit enhancement of biodiversity values.

4.1.2. Degree to which biodiversity impacts are mitigated

The results (see Table 2) suggest a tendency towards mitigation such that "no net loss" is achieved, which aligns with the previous results where mitigation through the mitigation hierarchy is predominant. Mitigating as a "net gain" is generally less practiced, except for Danish and Spanish SEAs. With that said, the prominence of "no net loss" measures in EIAs exceed that of SEAs in all countries as do the "net gain" measures in all countries except Germany. The lesser use of "no net loss" as a goal for mitigation is critical as such a practice could promote a proactive development of biodiversity rather than only protection. The results highlight that the remaining biodiversity impacts are not explicitly mitigated to "no net loss" nor "net gain" and that, in these instances, there may be some biodiversity loss which is not assessed as 'significant'. It should again be noted that each EA report can contribute to more than one of the columns in the table, meaning it can include more than one element, and some reports may not include any elements at all. Thus, the percentages in the table do not add up to 100 %.

Table 1
An overview of percentage of reports using the three approaches to mitigation. The absolute numbers of reports are included in parentheses.

			Biodiversity impacts are mitigated:		
		In accordance with the mitigation hierarchy	Based on residual impact	Through enhancing biodiversity values	None of these
Denmark	SEA (*N* = 45)	2 % (1)	4 % (2)	9 % (4)	85 % (38)
	EIA (*N* = 65)	20 % (13)	11 % (7)	9 % (6)	71 % (46)
Spain	SEA (*N* = 12)	50 % (6)	0 % (0)	0 % (0)	50 % (6)
	EIA (*N* = 8)	13 % (1)	25 % (2)	13 % (1)	62 % (5)
Portugal	SEA (*N* = 21)	5 % (1)	0 % (0)	0 % (0)	95 % (20)
	EIA (*N* = 20)	95 % (19)	0 % (0)	15 % (3)	5 % (1)
Germany	SEA (*N* = 10)	50 % (5)	0 % (0)	30 % (3)	20 % (2)
	EIA (N = 10)	100 % (10)	0 % (0)	0 % (0)	0 % (0)

Table 2
An overview of how percentage of reports aiming to achieve "no net loss" or "net gain" through mitigation measures. The absolute numbers of reports are included in parentheses.

		Biodiversity impacts are mitigated so that "no net loss" is achieved	Biodiversity impacts are mitigated so that "net gain" is achieved	None of these
Denmark	SEA (N = 45)	2 % (1)	2 % (1)	96 % (43)
	EIA (*N* = 65)	8 % (5)	3 % (2)	89 % (58)
Spain	SEA (*N* = 12)	8 % (1)	17 % (2)	75 % (92)
	EIA (*N* = 8)	63 % (5)	25 % (2)	13 % (1)
Portugal	SEA (N = 21)	5 % (1)	0 % (0)	95 % (20)
	EIA (*N* = 20)	85 % (17)	15 % (3)	10 % (2)
Germany	SEA (N = 10)	60 % (6)	30 % (3)	30 % (3)
	EIA (*N* = 10)	90 % (9)	10 % (1)	10 % (1)

4.1.3. How mitigation measures are worded

Wording that describes the degree to which implementation is required differs according to country context. In Denmark, most implementation, especially at the EIA level, is described as "must". This can likely be explained through the relation to requirements of the H/B Directives, which require EIAs to specify their mitigation measures. This compares to the approximately 22 % to 25 % of the reports that use the least binding "can" associated with implementation. In Spain, "should" is the most common phrasing, meaning that the measure comes as a suggestion where implementation is advised but not enforced. Contrary to Denmark, Portugal, and Germany, Spain does not use "can", meaning that "should" is the most optional form of implementation in their country context. In Portugal, SEA measures are often referred to as "can", albeit only 5 % of the total reports. EIA reports exhibit mostly measures of the least binding requirements "can" and "should" at 40 % each, with approximately 15 % that "must" be implemented. Lastly, mitigation measures in Germany across both SEAs and EIAs are optional, described as "can". However, "should" is also prominent in SEAs at 30 % of the reports and "must" is prominent in EIAs at 40 % of reports. Last, there are instances where reports use none of the analyzed wordings. This can point to other possible wordings being used or perhaps that the wording is not distinct enough to be classified. Regarding Table 3, it should also here be noted that each EA report can contribute to more than one of the columns in the table, meaning it can include more than one element, and some reports may not include any elements at all or may not have such specific wording. Thus, the percentages in the table do not add up to 100 %.

4.2. Mitigation strategies in the Danish case study

A closer examination of data from 51 selected Danish SEA and EIA reports related to spatial planning was carried out. The study was focused on the key aspects described in Section 3.2.

Each of the 51 reports contained multiple measures tailored to the specific project or context. On average, SEA reports contain 4 mitigation measures per report, while EIA reports contain an average of 15

Table 3
An overview of percentage of reports using specific wordings to describe the strength of requirement for the proposed measures. The absolute numbers of reports are included in parentheses.

		As a "can"	As a "should"	As a "must" or "will be"	None of these
Denmark	SEA (N = 45)	22 % (10)	4 % (2)	27 % (12)	58 % (26)
	EIA (*N* = 65)	25 % (16)	9 % (6)	52 % (34)	34 % (32)
Spain	SEA (*N* = 12)	0 % (0)	83 % (10)	8 % (1)	17 % (21)
	EIA (*N* = 8)	0 % (0)	63 % (5)	63 % (5)	0 % (0)
Portugal	SEA (*N* = 21)	5 % (1)	0 % (0)	0 % (0)	95 % (20)
	EIA (*N* = 20)	40 % (8)	40 % (8)	15 % (3)	5 % (1)
Germany	SEA (*N* = 10)	40 % (4)	30 % (3)	10 % (1)	30 % (31)
	EIA (N = 10)	60 % (6)	10 % (1)	40 % (4)	10 % (1)

measures. This difference highlights the more detailed and project-specific nature of EIAs compared to SEAs, which are typically broader in scope and focus on strategic-level recommendations rather than project-specific actions. The higher number of measures in EIAs suggests that these assessments engage more directly with on-the-ground mitigation actions, requiring a greater level of specificity and detail to address the localized impacts of individual projects and implying variation in mitigation planning across EA levels.

4.2.1. *The types of mitigation and enhancement measures used*

Fig. 2 depicts the absolute number of mitigation and enhancement measures used across SEAs and EIAs, illustrating the diversity of approaches taken in each type of assessment. There were 361 measures in total, of which 144 are from SEAs and 217 are from EIAs.

A key observation is that "passage/corridors and vegetation" dominates in EIAs, reinforcing their role in mitigating habitat fragmentation and the need for ecological connectivity in project designs. "Timing" measures are more common in SEAs, aligning with their broader strategic scope. "Distance requirements" appear in both SEAs and EIAs, reflecting a practical approach to manage impacts near sensitive areas or habitats.

"Construction requirements" and "alternative design/technology" are more prominent in EIAs, crucial for reducing disturbances during the construction phase. "Nature management/maintenance" and "rehabilitation" are common in both SEAs and EIAs. However, SEAs slightly favor "preserving land use purposes" and "nature management/maintenance", whereas "rehabilitation" is more prevalent in EIAs, likely as a response to immediate project impacts needing site restoration.

The "other" category is prominent in both EIAs and SEAs, encompassing various mitigation strategies not fitting predefined types. In SEAs, it often refers to setting requirements for further investigations and specifying fences, while in EIAs, it includes fence specification and measures related to introduced species and/or monitoring. A notable number of measures in SEAs are marked as "not specified", indicating that many actions are deferred for further clarification or decisions in subsequent planning stages, risking delayed or incomplete implementation.

4.2.2. *What the measures are aimed at mitigating or enhancing*

The measures in the reports primarily target natural habitats and specific species, which vary in legal protection from strong protection by EU regulation (like Natura 2000 areas and Annex IV species) to more general national legislations generally providing less stringent safeguards. Some recipients lack specific legal protection. The analysis also found instances where measures fail to clearly specify the protected habitat or species, often refering to broad and non-specific types (see Table 4).

Fig. 3 presents the distribution of mitigation and enhancement measures by recipient type and protection level. Key differences include:

1. EIA reports focus on strongly protected species directly impacted by projects, whereas SEAs prioritize broader ecological networks, regional biodiversity, and non-specific species or habitats.
2. EIAs typically include species-specific mitigation, like fauna passages for deer and amphibians, while SEAs aim to maintain connectivity and the functionality of ecological corridors for broader species groups.

Further, there is a noticeable emphasis on nationally protected habitats.

The analysis a significant number of measures categorizes as "no identification", using vague terms like "nature" or "mammals" without specifying species, habitats, or legal protection. This lack of specificity undermines misalignment with best practices in environmental compliance, such as those required by the H/B Directives, potentially leading to ambiguous and less effective mitigation efforts. These generic references suggest general biodiversity concerns but lack the details necessary for precise action or enforcement, risking inconsistent or

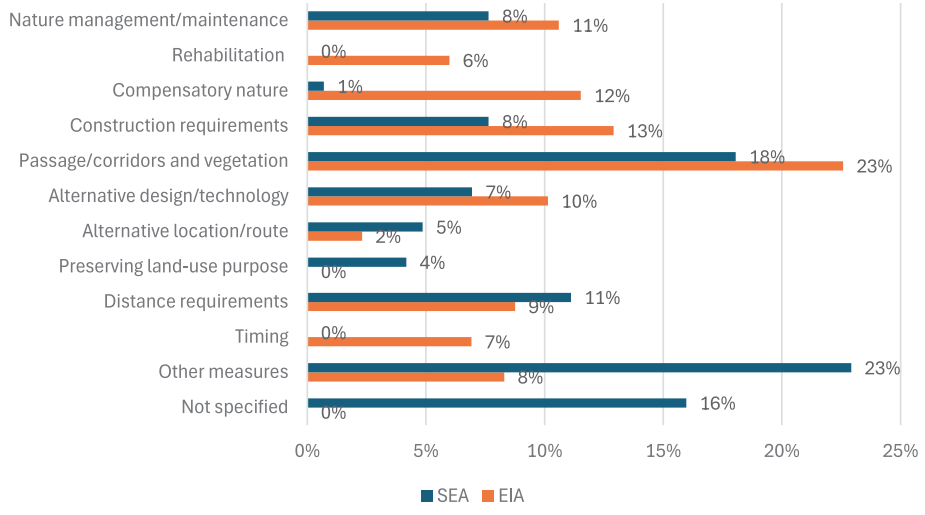

Fig. 2. Measures distributed on specific measure types.

Table 4
Categorization of recipients by protection level and specificity of the proposed mitigation and enhancement measures (* The European Union's H/B Directives, ** The Danish Nature Protection Act).

Recipient type/ protection level	Strong protection	Protection	No protection	No identification
Habitats	Habitats protected under EU nature directives* (e.g., wet meadows, fences, rivers and streams)	Habitats protected by national law** (e.g., lakes, bogs, meadows, heathlands)	Habitats not protected (e.g. urban habitats, grazing land)	Habitats not identified or specified in the reports (e.g., nature, vegetation, live fences, fauna passage)
Species	Species protected under EU nature directives, including Annex IV species* (e.g. some bat species, otter", hazel dormouse, great crested newt)	Species protected by national law only (e.g. mammals like hedgehog, amphibians like common toad and common frog)	Species not protected (e.g. fox, hare)	Species not identified or specified in the reports (e.g., animals, fish)

minimal protection.

4.2.3. *Differences in mitigation hierarchy application*

The application of the mitigation hierarchy within SEAs and EIAs reveals clear distinctions (see Fig. 4).

SEAs predominantly focus on avoidance, with nearly 50 % of measures aimed at preventing harm, reflecting their strategic, high-level nature. Approximately 25 % of the measures in SEAs minimize impacts, and up to 20 % enhance biodiversity. This reflects the broader sustainability goals often associated with strategic thinking in planning and assessment (Partidario, 2015, 2020). Repairing and off-setting are seldomly addressed at this level.

In contrast, EIAs prioritize minimizing impacts, with about 60 % of measures dedicated to this, reflecting their project-specific, immediate, and localized nature. Avoidance is less frequent at around 15 %, indicating that project-level avoidance is often limited by prior planning stages. Enhancement is minimal in EIAs, at about 5 %, and a significant 20 % of measures involve restoration and off-setting, indicating a reactive approach to managing residual impacts.

These findings underscore the inherent advantages of SEAs in facilitating a more integrated and proactive approach to biodiversity conservation.

4.2.4. *The strength of the formulation of measures*

In the analyzed EAs, 75 %–80 % of measures are obligatory ("must"), while only 3 % are described as a "prerequisite" for further assessment. A smaller fraction (15 %–25 %) exhibit weaker requirements, termed "can" or "should". Besides "should", which is more prominent for EIAs than SEAs, the percentages are similar between both. The over-representation of "must" reflects EA's role in enforcing legally binding measures to address biodiversity impacts. The strict language used in SEA and EIA is likely influenced by the strict regulatory framework through AA to ensure no adverse effects on site integrity.

Fig. 6 demonstrates that "must" is the predominant requirement in the mitigation hierarchy, accounting for nearly 90 % of avoidance measures, about 75 % of minimization measures, nearly 90 % of restoration measures, and just under 75 % of off-setting measures. This aligns with its overall prominence as shown in Fig. 5. Yet most notable is that while constituting a remarkably high percentage of the no-net-loss mitigation measures, the strong requirements constitute only 50 % of enhancement measures. This indicates a reluctance to commit strongly to enhancing biodiversity impacts compared to minimizing, repairing,

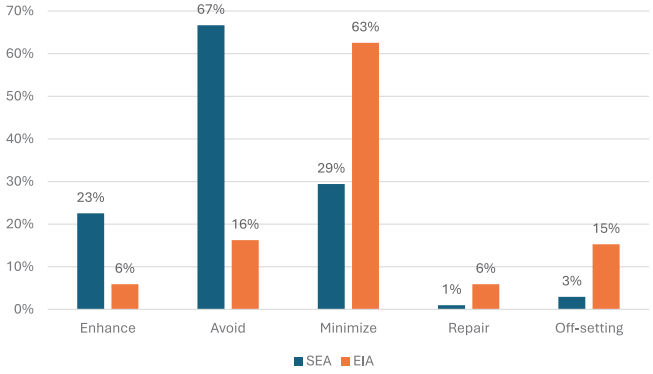

Fig. 4. The distribution of measures according to the levels of the mitigation hierarchy.

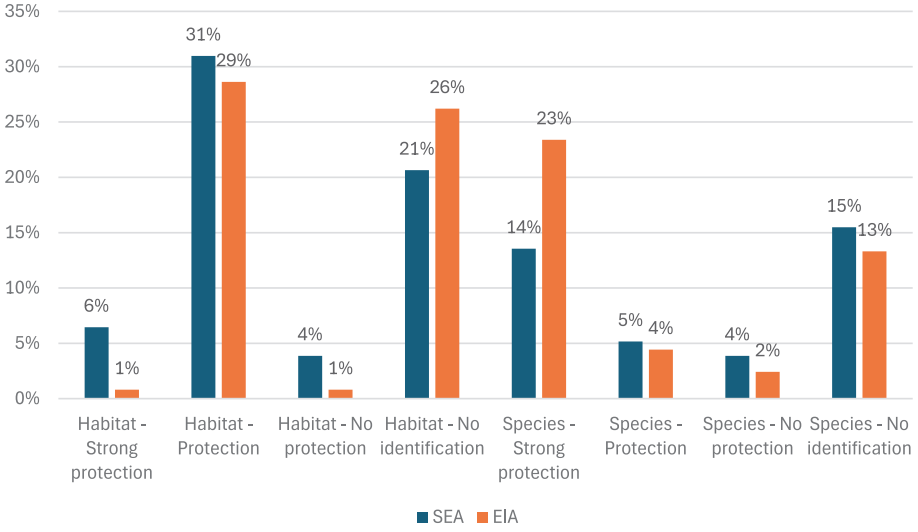

Fig. 3. Distribution of mitigation and enhancement measures (155 from SEAs and 248 from EIAs) by recipient type, protection level, habitat and species.

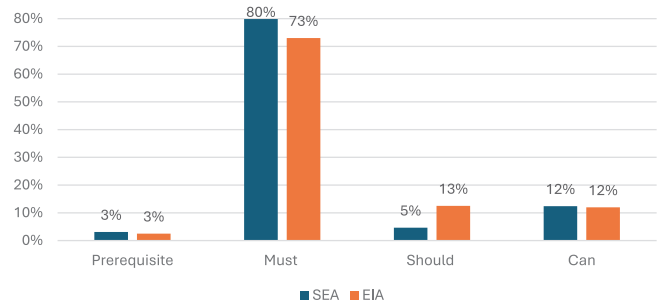

Fig. 5. An overview of the strength of implementation requirements in the reports.

or off-setting impacts. Enhancement is often described as "can" or "should" (at a combined 50 %), making up only 15 %–25 % of actions at the lower levels in the hierarchy.

4.2.5. *The implementation of measures in practice*

The implementation of mitigation and enhancement measures is critical for achieving the intended outcomes in both SEA and EIA (see Fig. 7). The level at which these measures are implemented involves the concept of tiering, facilitating effective communication between SEA and EIA.

In EIAs, all measures are expected to be ensured within the actual project, reflecting its project-level focus, where direct impacts are managed, and measures are embedded into the project's design and execution. This integration ensures clear accountability and effective implementation. This also reflects that measures at the concrete planning level often are legally binding and crucial for project approval (Bhateria, 2024).

In SEAs, the process is more nuanced. About half of the measures are directly integrated into the plan, while the rest are deferred to subsequent planning stages or are addressed in EIAs for individual projects within the broader SEA framework. This vertical tiering approach (Arts et al., 2011) allows for communicate within the same planning hierarchy. While this layered, or tiered, approach can initiate communication across different planning levels but introduces challenges due to its reliance on future actions and coordination, which this study does not explore.

5. Discussion and conclusion

The study examined how SEAs and EIAs in spatial planning and infrastructure development integrate biodiversity mitigation and enhancement measures, focusing on the need for transformative change in environmental governance. By analyzing reports from Spain, Portugal, Germany, and Denmark, and an in-depth examination of Danish cases, it identified key patterns and challenges in implementing

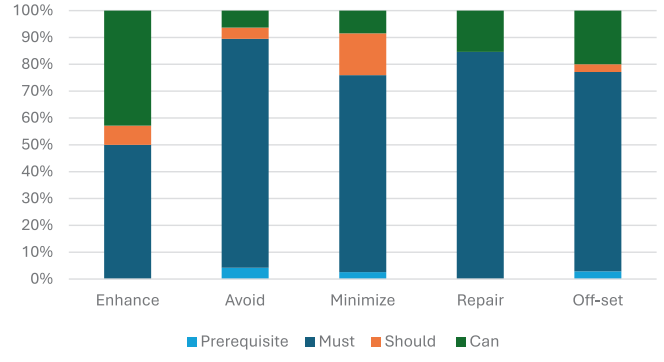

Fig. 6. The relative strength of the formulation of the mitigation measures at different levels of the mitigation hierarchy.

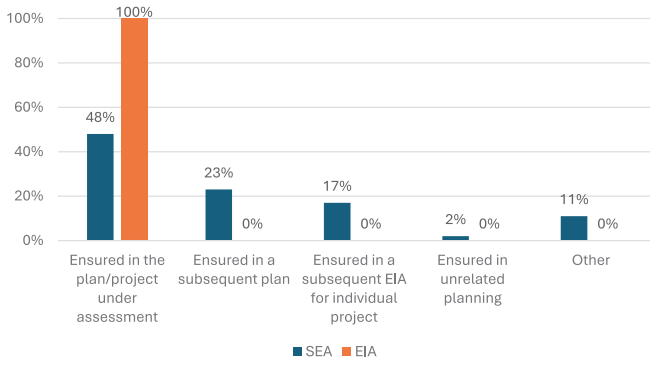

Fig. 7. The level at which mitigation measures are expected to be implemented.

the mitigation hierarchy.

5.1. *Summary of key findings*

The findings indicate that SEA and EIA reports predominantly focus on minimization as the primary strategy for managing biodiversity impacts, reflecting a reactive rather than proactive approach. This limits the full potential of the mitigation hierarchy, particularly in terms of avoidance and enhancement. Although avoidance measures are theoretically recognized by EU Directives, they are underutilized in project level EIAs. SEA, conversely, are more likely to incorporate strategic-level avoidance and enhancement, due to their broader planning scope. However, without effective integration across planning and project implementation tiers, the realization of these measures remains challenging.

The study highlights the limited use of proactive enhancement measures aimed at actively improving biodiversity beyond baseline conditions, despite widespread discussion in transformative environmental discourse (e.g., Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019). In practice, EIAs primarily focus on reactive strategies like minimization, restoration, and off-setting, rather than creating biodiversity gains. SEAs mention enhancement measures more frequently, and the findings underline the critical role of SEA in promoting not only the avoidance of negative biodiversity impacts but also the enhancement of positive outcomes. Nevertheless, the measures typically lack strong legal enforcement, reducing their transformative potential.

The analysis further reveals a challenge in the tiering between SEA and EIA processes. SEAs at the strategic level may propose measures for later planning stages or EIAs, but without clear follow-up mechanisms, these actions risk being weakened or lost as projects progress. This addresses the flawed monitoring and follow-up identified in studies such as Mäkeläinen and Lehikoinen (2021), Cares et al. (2023), and Gannon (2021), and indicate the need for better coordination between strategic- and project-level planning to ensure continuity and effectiveness in biodiversity protection.

5.2. *Implications for mitigation and enhancement in environmental governance*

The findings underline several important implications for the role of mitigation and enhancement measures in environmental governance, particularly in the context of spatial planning and infrastructure development.

5.2.1. *Strengthening regulatory framework for enhancement*

Under the current SEA and EIA Directives, mitigation measures to avoid, minimize, restore, and off-set biodiversity impacts are mandated, but not enhancement measures. As a result, opportunities to improve

biodiversity are missed, particularly in EIAs, which focus more on mitigating harm rather than creating net gains for ecosystems.

SEAs, with their broader strategic scope, provide a more feasible platform for formally integrating enhancement measures. They typically involve an authority as the proponent, allowing for the mandate and implementation of strategies that exceed mere mitigation. In contrast, the project-specific and legally constrained nature of EIAs limits their ability to formally include enhancement measures. Effective tiering between planning levels is crucial for enhancing biodiversity across all planning levels, with strategic decisions in SEAs potentially informing and enhancing lower-level planning and project. However, the current regulatory framework does not align with the growing call for transformative change to tackle biodiversity loss (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019; Wittmer et al., 2021). Damiens et al. (2021) argue that "Without deep structural changes, 'no net loss' and offsetting are at high risk of being mobilized as 'symbolic instruments', discursively acting to divert attention away from more transformative action limiting and reversing the depletion of biological diversity." (p. 176).

To tackle the global biodiversity crisis effectively, EA must evolve move beyond mere mitigation to make biodiversity enhancement a central element of environmental governance. This necessitates revising the directives to explicitly require enhancement measures, especially SEAs, to align with current scientific understanding and the urgency of the biodiversity crisis.

5.2.2. Ensuring strong, enforceable language

As illustrated, the effectiveness of mitigation and enhancement measures in EA reports is significantly influenced by their language clarity and enforcement. Measures stated with mandatory terms like "must" or "shall"' are more likely to be implemented than those with optional terms like "can" and "should". The analysis showed that 75 %–80 % of measures are obligatory, yet enhancement measures are often described in vague, non-binding terms, diminishing their implementation potential. To secure real biodiversity gains, stronger enforceable language needs to be consistently applied to all critical measures, including enhancements.

5.2.3. Improving tiering and coordination between SEA and EIA

As the results of this research show, enhancement and avoidance measures are most often recognized at the strategic planning levels through SEAs. Yet, while EIAs, operating at the lowest planning tier, ensure immediate action, SEAs operate within a tiered structure where mitigation measures are often deferred to later plans or EIAs, nearly 50 % of the time. Literature recognizes benefits when SEA frames lower-tier actions (Arts et al., 2011) and of addressing the right decisions at the appropriate level of planning (Therivel and González, 2021). Yet tiering (of i.e. biodiversity objectives) is often incomplete or absent (Gallardo and Bond, 2024). This reliance on future tiers poses risks of disrupted or failed implementation. If the transition from SEA to EIA is not seamless, strategic measures may not fully materialize at the project level, and the complexity of other plans and mechanisms complicates effective outcomes. Thus, ensuring early consideration of enhancement and can through delegation of future decisions to later levels promote that enhancement at the strategic level is vital, but it requires strong mechanisms for coordination and accountability across planning and assessment levels to mitigate implementation risks.

5.3. Moving towards transformative change

The global biodiversity crisis necessitates a proactive, transformative approach to conservation, urging the evolution of environmental governance frameworks like EAs to include enhancement for addressing root causes of biodiversity decline. To effectively support this transformation, EAs should be integrated at the earliest stages of the planning process. Incorporating these assessments at the outset ensures that critical decisions are informed by robust biodiversity considerations, providing a foundation for proactive environmental safeguards rather than reactive mitigation. It also allows for planning levels to better communicate with one another through effective tiering, thereby ensuring that mitigation and enhancement measures are addressed at the appropriate planning levels and that strategic biodiversity considerations are effectively accounted for when implementation occurs.

Additionally, transformative change requires strengthening "avoidance" in the mitigation hierarchy to prioritize biodiversity preservation upfront, rather than relying on minimization or offsetting. Reinforcing the avoidance principles would prioritize the prevention of adverse impacts before they occur, aligning SEA and EIA practices with a more precautionary-focused approach. This shift towards net-positive outcomes allows projects to contribute positively to ecosystems.

In conclusion, transformative environmental governance requires SEAs and EIAs to be strengthened through regulatory reform, stronger language, and better coordination across planning tiers. Formalizing enhancement and mainstreaming ecosystem services are critical steps. While this study focuses on EU practices, its implications extend internationally, suggesting a need for future research to assess how different governance systems influence enhancement in EAs globally.

5.4. Limitations of the study

This analysis relies solely on SEA and EIA reports, which, while informative, may not reflect the full scope of measures integrated into plans or projects. Some measures might have been implemented or adapted before the drafting of these reports, details of which may not be evident in the final documents. Furthermore, measures proposed may evolve during implementation due to various constraints like financial or physical limitations. To address these limitations, preliminary results were discussed in a webinar with practitioners and EA researchers (Ravn Boess et al., 2024), and their feedback the insights provided have been accounted for in our analysis.

Additionally, the study primarily examines Danish reports, limiting its applicability to broader European or global contexts. Variations in national regulations, environmental priorities, and practices mean that findings from Denmark may not directly translate to other settings without further comparative studies.

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CRediT authorship contribution statement

Lone Kørnøv: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Visualization. **Emilia Ravn Boess:** Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Visualization. **Søren Qvist Eliasen:** Investigation, Formal analysis, Data curation, Writing – original draft, Visualization. **Sanne Vammen Larsen:** Methodology, Investigation, Formal analysis, Data curation, Writing – original draft. **Karla E. Locher-Krause:** Writing – review & editing. **Yuanzao Zhu:** Writing – review & editing. **Heidi Wittmer:** Writing – review & editing. **Lia Borges Laporta:** Writing – review & editing. **Davide Geneletti:** Writing – review & editing. **Margarida Barata Monteiro:** Writing – review & editing. **Maria Rosario Partidario:** Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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