Causal Map Tool of Cause-Effect Relations and Biodiversity Mitigation Hierarchy Connected to Spatial Planning

Kørnøv, Lone; Ravn Boess, Emilia; Gordon, Johanna; Eliasen, Søren Qvist ; Partidario, Maria Rosario; Monteiro, Margarida B.

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D2.2 CAUSAL MAP TOOL OF CAUSE-EFFECT RELATIONS AND BIODIVERSITY MITIGATION HIERARCHY CONNECTED TO SPATIAL PLANNING

WP 2 Environmental Assessment Instruments (EAI)

Authors: Lone Kørnøv (AAU), Emilia Ravn Boess (AAU), Johanna S. Gordon (AAU), Søren Qvist Eliasen (AAU)

Contributing Author: Maria Rosario Partidário (IST) and Margarida Monteiro (IST)

BioValue

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Project Coordinator	Maria Rosario Partidario University of Lisbon - Instituto Superior Técnico mariapartidario@tecnico.ulisboa.pt
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1.0		AAU	Lone Kørnøv, Emilia Ravn Boess, Johanna Gordon, Søren Qvist Eliasen **Contributing authors**: Maria Rosario Partidário

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1 Introduction

For terrestrial and freshwater ecosystems, land-use change has had the largest relative negative impact on nature since 1970

IPBES, 2019

Among the direct drivers of biodiversity loss, land-use change stands out as having the most significant global impact – and relates to modification of natural environments into urban, agricultural, or industrial uses (IPBES, 2019). This change in land use can result in destruction, fragmentation or degradation of habitats, and ultimately lead to biodiversity loss. Land-use change, along the four other main direct drivers, stems from underlying causes, known as the indirect drivers (see Figure 1).

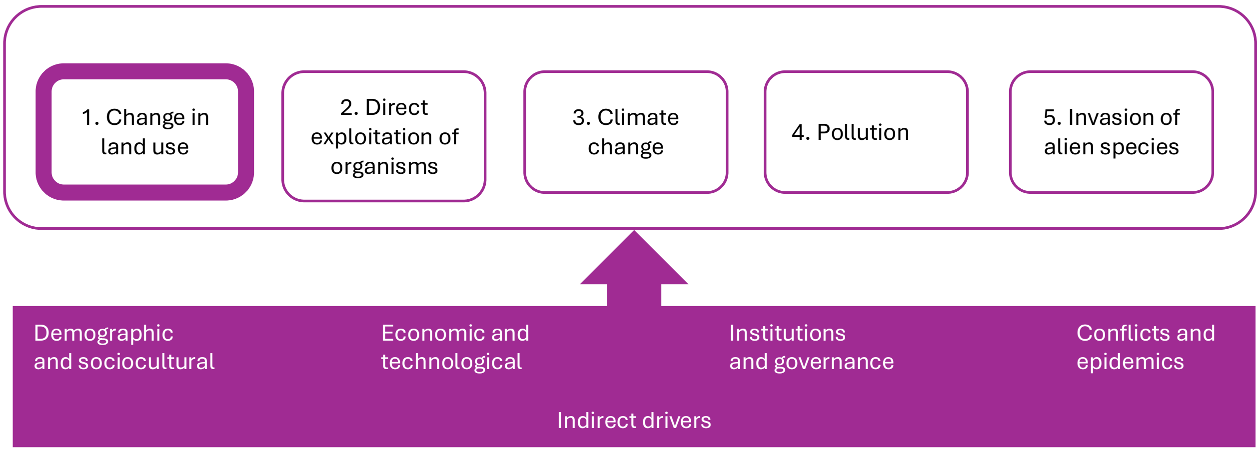

Figure 1: Direct and indirect drivers of biodiversity loss (Source: text from IPBES, 2019).

1.1 The role of spatial planning

Spatial planning plays a critical role in tackling biodiversity loss through allocating land for various uses and placing conditions on future land uses. Spatial planning can mitigate the negative effects of land-use change by ensuring that development occurs in a way that considers ecological processes and preservation of fundamental habitats. Beyond mitigation, spatial planning also plays a role for actively enhancing biodiversity values by e.g., creating new habitats.

Focusing on land-use change through spatial planning also presents an opportunity to address the indirect drivers of biodiversity loss. Spatial planning can e.g., facilitate the transition to renewable energy sources, thereby mitigating climate change, or promote sustainable production and consumption patterns through designating areas for sustainable agriculture and forestry.

Spatial planning refers to the methods used largely by the public sector to influence the future distribution of activities in space. It is undertaken with the aims of creating a more rational territorial organization of land uses and the linkages between them, to balance demands for development with the need to protect the environment, and to achieve social economic objectives.

Spatial planning embraces measures to co-ordinate the spatial impacts of other sectoral policies, to achieve a more even distribution of economic development between regions than would otherwise be created by market forces, and to regulate the conversion of land and property uses.

European Commission, 1997: 24

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1.2 Need for increasing the transformative potential of environmental assessment instruments in spatial planning processes

In the pressing global context of biodiversity loss, with its impact on extinction-risk, ecosystem services and human well-being, transformative change is needed.

Through comprehensive spatial planning, including both the allocation of land and conditions on its future usage, it is possible to not only mitigate land-use change induced negative impacts but also to enhance biodiversity values. By addressing both the direct and indirect drivers of biodiversity loss, spatial planning can contribute to a more sustainable and biodiverse future – and play a role for transformative change.

Transformative change is a fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values.

IPBES, 2019

To achieve this, the transformative potential of environmental assessment instruments within spatial planning processes must be increased. This is the focus of Task 2.3 in the BioValue project, which aims to "understand causal mechanisms in spatial planning and infrastructure development used in SEA and EIA to explore how these might be improved to enhance its role in generating transformative actions for biodiversity" (BioValue project description).

Task 2.3 involves annotating and analyzing causalities in collected Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) reports, leading to a causal-map tool of cause-effect relations and biodiversity mitigation hierarchy connected to spatial planning and management instruments.

Building on this foundation, the systems thinking approach offers a powerful means of mapping and analyzing causal connections involved in potential spatial changes, as depicted in Causal-loop Diagrams (CLD). This approach not only complements but significantly enhances the effectiveness of environmental assessment by identifying the most critical elements, processes and dynamics resulting from interconnectivity and feedback. These factors are crucial to be addressed in decisions and use of instruments in the spatial planning process. By understanding not only the direct impacts but also the feedback mechanisms, focus and instruments of spatial planning can address self-generating processes, supporting the planning goals. As such it increases the transformative potential of environmental assessment instruments in spatial planning processes.

Moreover, systems analysis reveals system structures and resulting dynamic processes, which are generated by the interplay of positive (reinforcing) and negative (balancing) feedback loops (Sterman, 2000). Both mechanisms are crucial for understanding causal connections and non-linear dynamics between the elements under pressure of the impacts of plans, programs and projects. It also facilitates the identification of feasible leverage points, which are critical points in the system that can be influenced in order to receive a better outcome. Identifying these points can lead to informed recommendations concerning opportunities for measures to avoid, minimize, or compensate potential impacts as well as to enhance biodiversity standards (Meadows, 1997).

Thus, by integrating these improved SEA and EIA instruments within spatial planning processes, the transformative potential to enhance biodiversity and achieve sustainable development goals can be significantly increased. The actual effects of this understanding of the causal effects, depends on the actual planning process and context in which it is applied.

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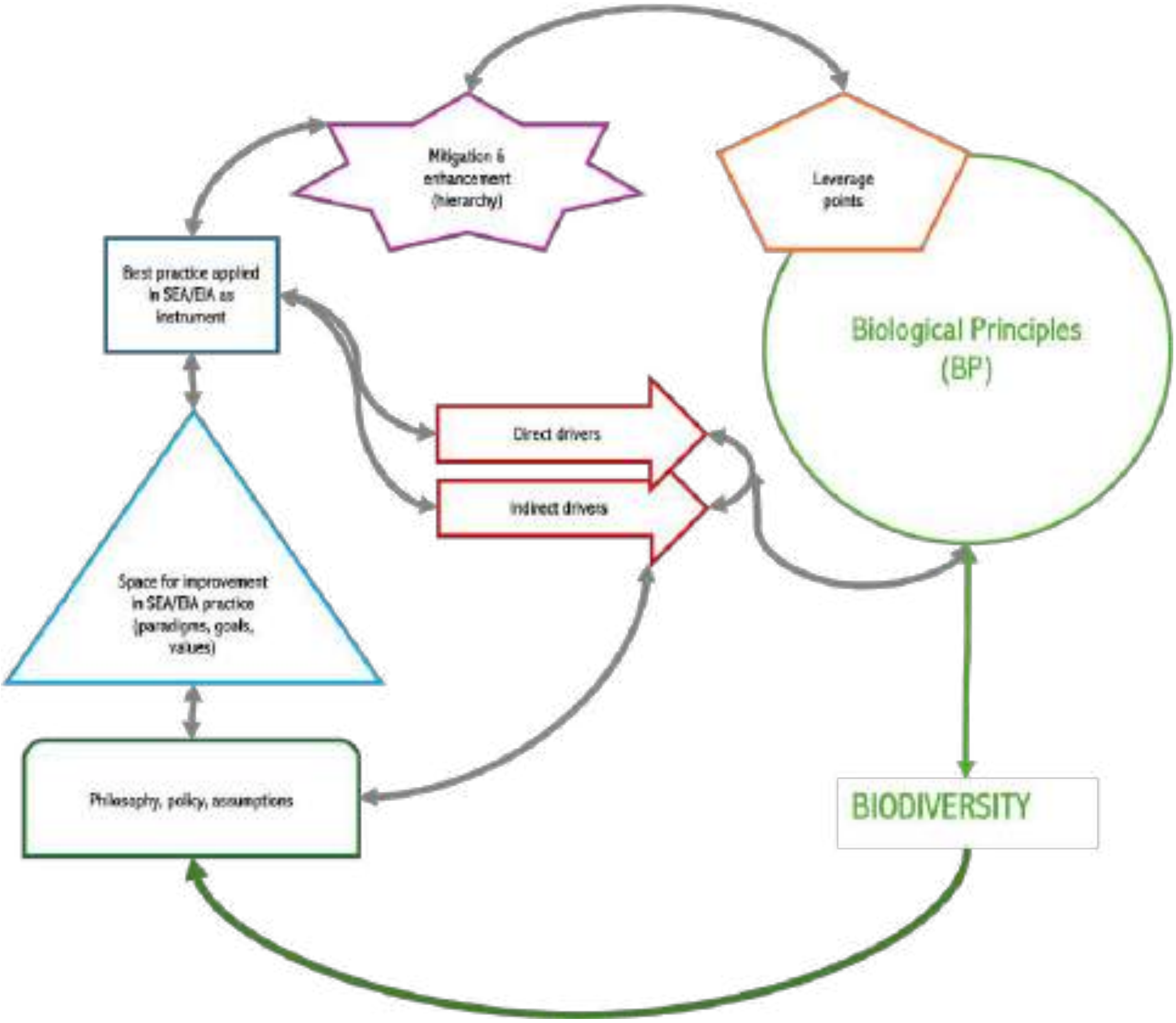

Figure 2: Schematic framework of approach in WP2 towards Transformative Change for Biodiversity inspired by Partidário (2024). (Source: Authors' model).

The framework of approach in WP2 toward transformative change for biodiversity is illustrated in Figure 2. Best practices with SEA and EIA as main instruments are identified and inform the choice of mitigation and enhancement measures in accordance with the established hierarchy. They are informed by the policies, assumptions, and philosophy that assist the practice of spatial planning, which determine the nature and type of decisions expressed through direct and indirect drivers. The understanding of the dynamics intrinsic to the Biological Principles allows for the identification of feasible leverage points for enhancement and mitigation to enhance biodiversity. This understanding also allows for closing a learning loop over time, dynamically increasing the policies, assumptions, and philosophy to increase the space for improvement in favor of decision-making and transformative change for biodiversity.

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The transformative change of the environmental assessment instruments such as SEA and EIA is based on their ability in clarifying the impacts, proposing mitigation and enhancement measures, and identifying possible reinforcing processes. These tools serve as crucial decision support mechanisms within the spatial planning process, providing authorities and other stakeholders with the necessary knowledge to inform transformative actions.

However, the effectiveness of SEA and EIA in driving transformative changes depends not only on their technical rigor but also on how their findings are utilized within the broader context of spatial planning. While these instruments contribute valuable insights and guidance, their true transformative impact emerges when their outcomes are effectively linked to other instruments and processes within the spatial planning framework. This aligns with the Transformative Change Framework outlined by Locher-Krause et al. (2023), which emphasizes the importance of integrating various instruments to achieve systemic change.

Thus, while SEA and EIA are powerful instruments on their own, their ability to drive transformative change for biodiversity is significantly enhanced when integrated with spatial planning and supported by complementary instruments such as financial and economic instruments.

Task 2.3, along with the related work on causalities mapped and analyzed in SEA and EIA reports, is rooted in the BioValue project, as detailed in Section 1.3.

1.3 Anchoring in the BioValue project

The BioValue project represents a pioneering initiative that seeks to “safeguard and enhance biodiversity through transformative change in spatial policymaking, planning practices and infrastructure development, upscaling opportunities for valuing biodiversity” (Partidário, 2023: 4). With its focus on spatial planning, the BioValue project plays a critical role in the broader context of the EU’s Biodiversity Strategy, which seeks to achieve nature protection, ecosystem restoration, and resilient network establishment.

This report operates within the transformative framework, as illustrated in Figure 3 below. It applies systems thinking for developing the causal-loop tool, which has the potential to significantly increase the transformative impact of environmental assessments (SEA/EIAs).

By contributing to transformative knowledge (component 2 in Figure 3) this report provides robust knowledge and decision support for transformative governance (component 5 in Figure 3). It can enlighten discussions among relevant actors and identifies areas for intervention to direct the dynamics of the system towards transformative change for biodiversity.

The report is anchored in the project’s Work Package 2 (WP2), which focuses on the critical evaluation and enhancement of environmental assessment instruments.

Within this framework, the emphasis on biodiversity within the environmental assessment, aligns with BioValue’s primary ambition: “Spatial planning safeguards, restores, allows recovery and enhances biodiversity”. This includes key aspects such as “Protected areas and bio corridors”, as well as promoting “Compact Cities” under the second ambition: “Spatial planning significantly contributes to balanced and responsible consumption and production without external social and environmental costs”. These goals are further elaborated in the “Analytical framework” detailed and specified for application within BioValue WP4 (Wittmer et al., 2021 in Locher-Krause et al., 2023).

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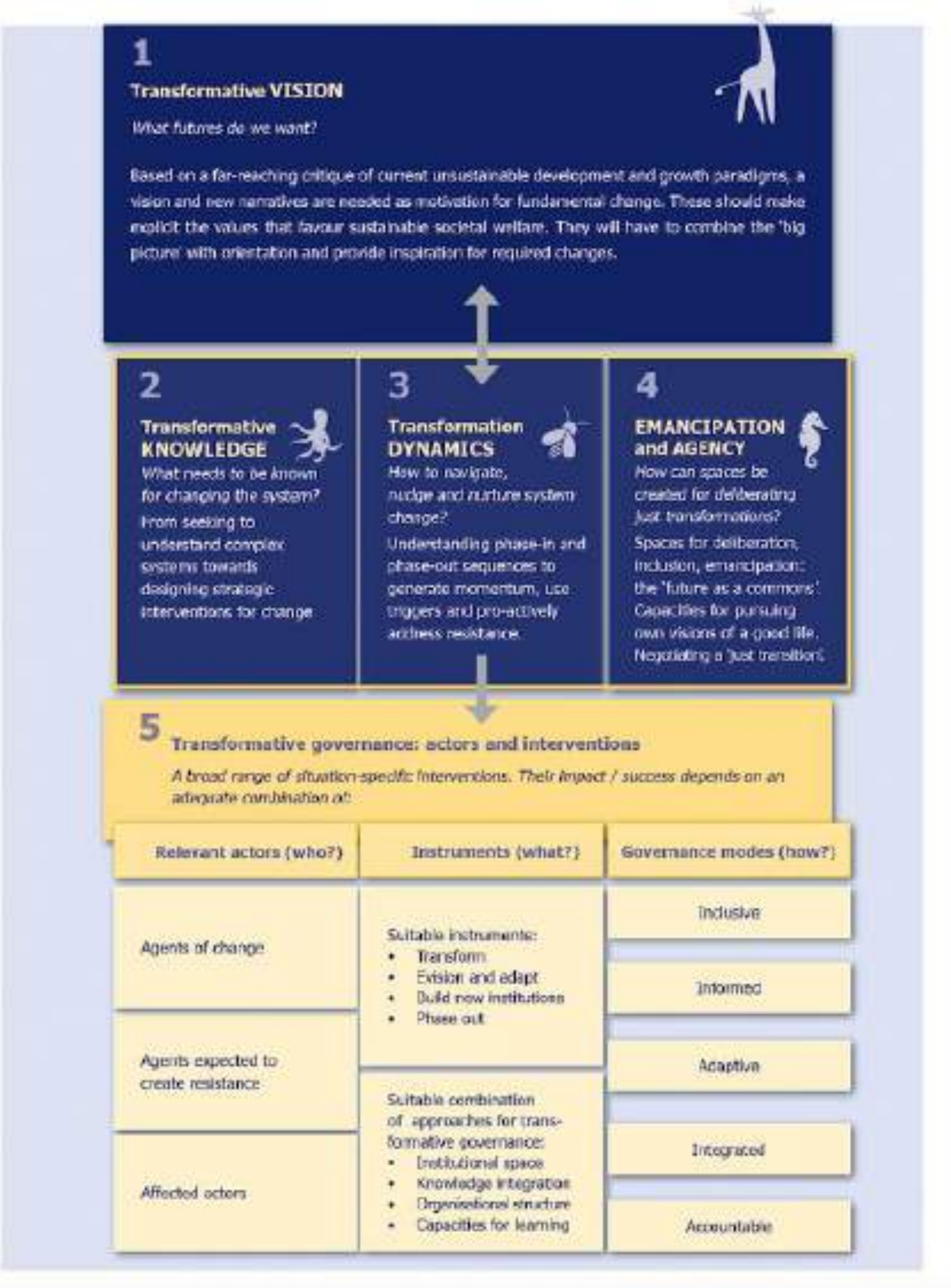

Figure 3: Transformative change framework (Source: Wittmer et al., 2021: 31)

In addition to analyzing causalities in SEA and EIA reports, the report draws on contributions from WP1, "Spatial planning and management", WP3, "Economic and financial instruments" and WP4, "Transformative change", which focus on arenas for transformation in Portugal, Italy and Germany.

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WP1 has offered critical input, including expert perspectives on best practices for integrating biodiversity into spatial planning (see Hoyos-Rojas et al., 2023) and valuable insights on incorporating ecosystem services into spatial planning through e.g. environmental assessment processes (see Laporta et al., 2023). Meanwhile, WP3 has provided a comprehensive overview of financial and economic instruments, some of which are applicable to enhancing environmental assessments (see Zhu et al., 2023).

Furthermore, to effectively align the causal-loop tool with the BioValue transformation arenas, the insights from WP4 have been instrumental. Specifically, findings from transformative workshops (see Monteiro et al., 2024) and the detailed exploration of generic spatial planning processes (see Partidário, 2024) have significantly enriched the report analysis.

By integrating these diverse and interdisciplinary inputs, the report aims to offer a comprehensive and systemic contribution, enhancing the effectiveness of environmental assessment instruments and thereby contributing to the overarching objectives of the BioValue project.

1.4 Systems thinking and causal-loop diagrams as a valuable tool for environmental assessment, planning and biodiversity

A key component of the methodology in WP2 involves systems thinking, including the development of causal-loop diagrams (CLDs), a tool that enables the visualization and analysis of complex systems and their various interdependencies.

The development and use of CLDs in the BioValue project is aligned with the need to address complex, interrelated challenges in biodiversity enhancement through spatial planning processes, and hereby not only assists in understanding complexities but also facilitates planning and environmental assessments that are informed by an integrated view of the system's dynamics.

> *CLDs describe the reality through causalities between variables and how they form a dynamic circular influence. We want to observe the world through feedback rather than linearly. We want to observe repeated patterns that may be used to predict the behavior in the problem. It's about understanding cause and effect.*
>
> Haraldson, 2004: 21

The adoption of CLDs in the context of BioValue aims to fulfill several key objectives:

1. *Visualize the complex systems in spatial planning for biodiversity*
   Biodiversity is intrinsically a highly complex system, influenced by and interacting with e.g., the biological, planning and economic system. CLDs are used to visualize both the biological system and its interaction with other systems. In that way, CLDs help to understand the relationships that exist within and between spatial planning, economic and financial instruments, environmental mitigation and the impacts for biodiversity.

2. *Identify feedback loops*
   Biodiversity outcomes are the result of numerous interacting variables within spatial planning systems. CLDs help identify both reinforcing and balancing feedback loops that can either accelerate or stabilize system dynamics. For example, a reinforcing loop might involve expanding an existing nature area, which in turn enhances the growth of a species population and further increases the area's biodiversity value. By identifying loops, planners and policy makers are supported in their evaluation and management of the outcomes of their decisions.

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3. *Identify leverage points*
   Leverage points, according to Donella Meadows' (1997), are strategic places within a complex system where a small change can produce significant, lasting improvements. Meadows identifies 12 leverage points, ranging from more tangible elements like adjusting constants and system structure to deeper, more influential ones like altering the goals of the system, changing the rules, or shifting the mindset or paradigm that drives the system. The higher the leverage point on her list, the more impactful it can be, although these are also often the most difficult to influence. The ranking of leverage points also relates to the direct and indirect drivers in the system. Leverage points directly addressing variables in the system (e.g. a noise barrier), tend to operate at the level of direct drivers (noise barrier, less noise), where as the higher leverage points tend to address the indirect drives such as mindset. Informed decisions on where and how to intervene in a dynamic system are crucial in spatial planning to avoid fixes that fail and unwanted surprises, e.g., by applying certain mitigation measures.

4. *Enhance transformative capacity*
   The BioValue project seeks not only to understand but also to enhance the transformative capacity of spatial planning, environmental assessments, and financial instruments. CLDs facilitate this by showing how changes in one part of the system can lead to impacts elsewhere, thereby guiding the development of strategies and planning that can lead to substantial improvements in biodiversity outcomes.

5. *Integrate across instruments*
   One of the project's aims is to explore how different instruments – spatial planning, environmental assessment, and economic means – can be used together in a concerted effort. CLDs are useful for this purpose as they display how these instruments interact. This integrated view is essential for coordinating comprehensive and effective actions.

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1.5 Linking systems thinking to the generic spatial planning process

The adoption of systems thinking in the context of BioValue aims to enhance the potential of environmental assessment in planning processes. Figure 4 illustrates the generic planning process as outlined in the project. The generic planning process is a structured approach and designed to facilitate collaborative governance, engagement, and co-creation among multiple sectors, scales, governance levels, and actors. The process is a dynamic and iterative framework that ensures planning is systematic, inclusive and adaptive to changing conditions and new insights.

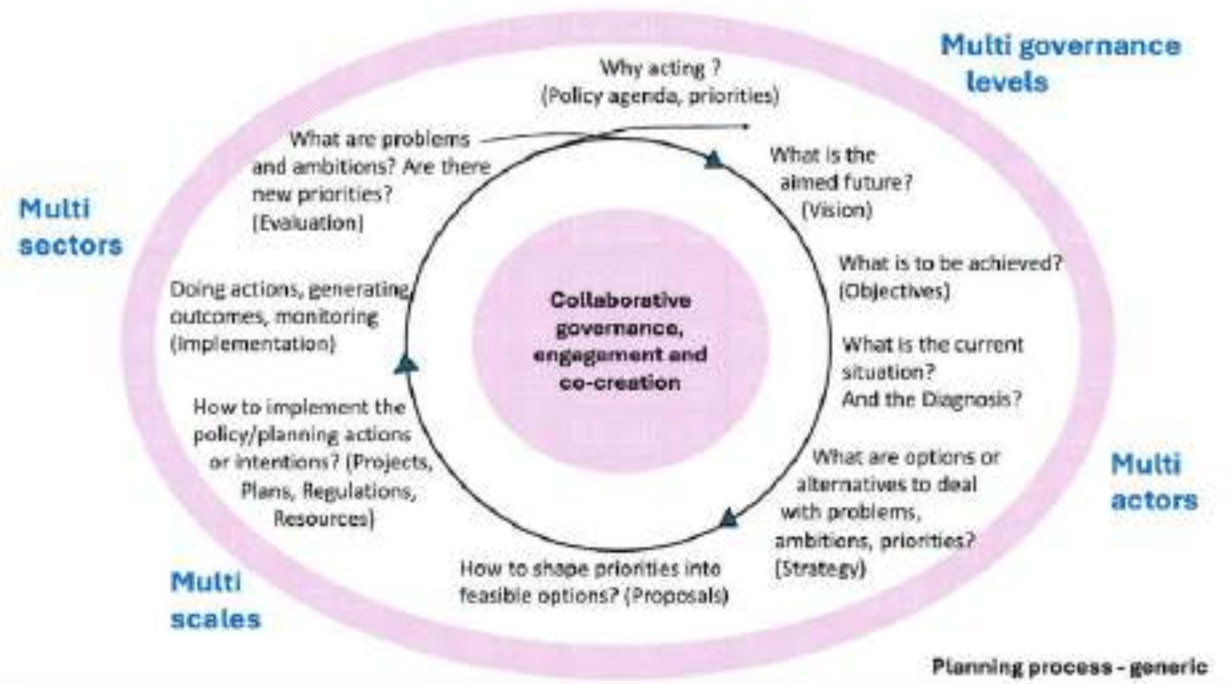

Figure 4: The generic representation of the cyclicals spatial planning process (Source: Partidário, 2024).

Linking systems thinking to the generic planning process through the use of CLDs can be beneficial at different stages. CLDs have the potential to facilitate a shared understanding of the challenges and to provide a shared understanding among the different actors involved throughout the various stages of the process. However, it is important to acknowledge that CLDs are one out of many tools that can support, but not guarantee, these outcomes.

What are problems and ambitions? Are there new priorities?

CLDs can assist in exploring a problem by exploring the causes or reasons why a problem arises, how they might be interconnected and interacting, and what potential effects the identified problem might have if no change is applied to the system. While CLDs can offer insights, the complexity of systems means that not all interconnections or consequences may be fully captured.

Why acting?

CLDs can help clarify the reasons and motivations for planning by visualizing the causal relationships that define the current biodiversity challenges. This foundational understanding can support the setting of the policy agenda and priorities by highlighting critical leverage points within the system, *i.e.* the points in the system that can be influenced in order to receive a better outcome. Nevertheless, it is important to recognize that CLDs offer a simplified model of reality, and their insights should be complemented with other forms of analysis.

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What is to be achieved?

CLDs can aid in setting objectives by illustrating how various factors interact and influence biodiversity outcomes. This can assist in defining goals that are ambitious and achievable, based on an understanding of the system dynamics and resulting behavior. However, the predictive power of CLDs is limited, and they should be seen as one part of a broader decision-making process.

What is the current situation?

CLDs can contribute to diagnosing the current state of biodiversity by mapping out existing conditions and identifying key variables and their interactions. This view can help in understanding the root causes of current issues and lays the groundwork for effective planning. But it is important to use CLDs in conjunction with empirical data and other analytical tools to ensure a comprehensive view.

What are options for alternatives?

CLDs allow for exploring different alternatives by adding or changing the system structure to see how different outputs can be achieved. This can facilitate discussions and evaluations of options in the process of forming decisions.

How to shape priorities into feasible outcomes.

CLDs can assist in qualitatively analyzing the alternatives and the effectiveness of proposed change. They can provide insights into how the entire system might be affected, including new interconnections and resulting feedback loops.

For guidance on interpreting the upcoming CLDs, please refer to Figure 5, below, which provides an explanation of how to approach and understand these diagrams within the BioValue framework. Additionally, Annex I include an example that specifically expounds on the interpretation of a CLD.

How to read the causal-loop diagrams

Causal-loop Diagrams (CLDs) are powerful tools used in systems thinking to visualize the feedback loops and causal relationships within a system. They help in understanding the dynamic behavior of complex systems by illustrating how different variables influence each other. CLDs consist of nodes representing variables and arrows indicating the direction and nature (positive or negative) of influence between them. The key elements of CLDs are presented below.

Signs/ components	
	Variables represented as nodes. Variables are the elements of the system being studied.
Arrows ⟶	Indicate the direction of influence from one variable to another. Each arrow has a polarity (positive or negative).
Positive polarity +	Variables change in the same direction: An increase in one variable leads to an increase in the other, or a decrease leads to a decrease. Sometimes the + is left away to reduce clutter and only – signs are depicted.
Negative polarity -	Variables change in opposite directions: An increase in one variable leads to a decrease in the other, or vice versa.
//	Delay in relation to the speed of the overall system.
Feedback loop	Circuits of arrows that show how variables influence each other in a closed path.
Reinforcing feedback loop R	Positive, reinforcing feedback loops drive change forward, like an upwards or downwards spiral.
Balancing feedback loop B	Negative feedback loops counteract reinforcing loops, with a balancing or self-correcting effect.

Figure 5: How to read the causal-loop diagrams

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2 Environmental Assessment Instruments and biodiversity

It is clear that 'business as usual' will neither achieve our climate change nor our biodiversity objectives. The time has come to make sure that we employ all available tools to tackle the threats. Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) are legally required and systematic tools, and as such, they are well suited to systematically tackle the problems.

EU Commission, 2013

2.1 Biodiversity and the environmental concept in environmental assessment

Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) are critical tools for evaluating, mitigating and enhancing environmental impacts of projects, programs, and plans. The primary purpose of SEA and EIA is to integrate environmental considerations into planning and decision-making processes to promote sustainable development. EIAs are applied to specific projects, and SEA on the other hand covers policies, plans and programs and thus incorporating a more strategic perspective.

Environmental assessment is recognized by the European Commission as an instrument expected to provide a critical basis for integrating biodiversity and ecosystem considerations into plans, programs and projects (EU 2013a, 2013b). Flora, fauna, and biodiversity are explicitly specified in the list of environmental factors to be assessed (EU 2001 and 2014). Albeit the SEA and EIA Directives are horizontal regulations within the EU's environmental policy framework, they play a crucial role integrating environmental considerations across multiple policy areas, with biodiversity being a significant area of focus.

The horizontal and integrative approach is emphasized by the broad concept of environment encompassing various factors in the two underlying directives. This integrative approach is closely related to systems thinking, which recognizes the interconnections between different environmental factors and their cumulative impact on sustainability. By adopting a systems thinking approach, SEA and EIA ensure that biodiversity, along with other critical environmental factors, is systematically considered, managing potential conflicts and synergies between biodiversity and other environmental issues (EU 2013a and b). Recognizing and integrating these environmental factors into planning processes is essential for promoting sustainable development and ensuring the health of ecosystems that support human life and various ecosystem services.

- *Flora, fauna, and biodiversity*
- *Population*
- *Human health*
- *Soil*
- *Land*
- *Water*
- *Air*
- *Climatic factors*
- *Material assets*
- *Cultural heritage*
- *Major accidents and/or disasters*
- *Resource efficiency*

EU 2001 and 2014

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2.2 Flora, fauna and biodiversity

The environmental factor of 'flora, fauna, and biodiversity' focuses on protecting individual species and biodiversity as a whole, including habitats and ecosystems. This protection is essential due to the interconnected nature of ecosystems, where the health of water, air, and soil directly impact species and their interactions.

Protecting flora, fauna, and biodiversity involves several strategies, such as conserving natural habitats, restoring degraded ecosystems, and implementing legal protections for threatened species. The EU's approach, exemplified by the Natura 2000 network and the listing of species in Appendix IV of the Habitats Directive, emphasizes the importance of conserving biodiversity at both species and ecosystem levels. This ensures the upholding of ecological functionality and genetic variation.

The Convention of Biological Diversity (CBD) defines biological diversity as 'the variability of living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Article 2)

EU Commission, 2013: 6

Different tools and approaches within the SEA and EIA instruments can be used to support the assessment of biodiversity as part of the processes. Table 1 provides an overview of selected tools and approaches.

Tools and approaches for assessment of biodiversity	EIA	SEA
Biodiversity offsetting	■	■
Biodiversity screening map	■	■
Confidence levels	■	■
Ecological surveys	■	
Critical factors		■
Ecosystem-based approaches	■	■
Ecosystem services approaches	■	■
Ecosystem services valuation	■	■
GIS and spatial analysis	■	■
Green infrastructure	■	■
Integrated Biodiversity Assessment Tool (IBAT) for business	■	
Integrated Biodiversity Assessment Tool (IBAT) for Research/Conservation Planning	■	
Life Cycle Assessment (LCA)	■	■
Natural capital approaches/Four-Capitals		■
Network analysis	■	■
Scenarios	■	■
Spheres of influence and Ecosystem chains	■	■
SWOT and STEEP analysis		■
Systems thinking and analysis, hereunder Causal-loop Diagrams	■	■

Table 1: Different tools and approaches for SEA and EIA assessments (Sources: The EIA column is based upon EU, 2013b, the SEA column is based upon EU, 2013a, and the last row is complementation based upon BioValue project).

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In the CLDs that are presented throughout this report, biodiversity is understood to be based upon three general pillars (see Figure 9): genetic diversity, species diversity, expressed in the number of species, and ecosystem diversity, expressed in the persistence of ecosystems. These components incorporate the "spatial dimension" and the "interactions" between the entities of biodiversity: "number, abundance, composition, spatial distribution, and interactions of genotypes, populations, species, functional types and traits, and landscape units in a given system" (Díaz et al., 2006: 1300).

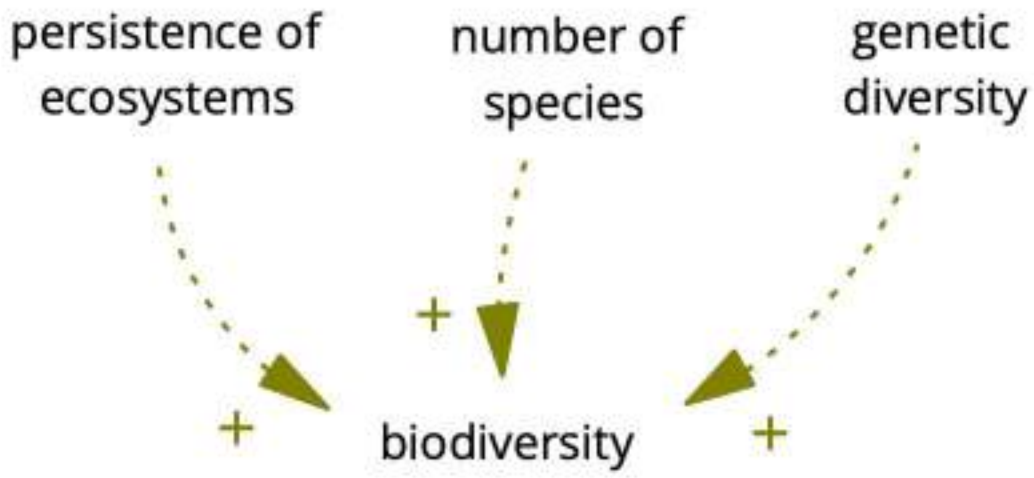

Figure 6: The three general pillars of biodiversity (Source: Own model.).

2.3 Distinction between nature areas and species – and levels of protection

In the report and in some of the developed CLDs, a distinction is made between nature areas and species, emphasizing the ecological roles and conservation needs of each category:

Nature areas, refer to distinct ecosystems or habitats such as forest, wetlands, and grasslands. Each nature area provides specific ecological functions and services, supporting various species and contributing to overall biodiversity.

Species refers to individual organisms that share common characteristics and can interbreed. Protecting species involves safeguarding plants, animals, fungi, and microorganisms.

Furthermore, the report and some of the CLDs refer to levels of protection of these nature areas and species. The levels of protection refer to three levels, namely strongly protected, protected and unprotected. These terms are used to indicate varying levels of conservation measures and regulatory frameworks applied to different areas or resources:

Strongly protected species and areas are those designated under international law and agreements, such as the EU Habitat Directive and Birds Directive. Examples include species listed in Annex IV of the Habitats Directive and areas designated as Natura 2000 sites. These species and areas receive

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stringent protection measures to prevent their degradation and ensure their conservation status remains favorable.

Protected species and areas are those designated under national, regional or local regulation. Examples include habitats listed under the Danish Nature Conservation Act as §3 nature. Examples of protected areas are heathland, salt marshes and pastures. While these habitats are protected, the regulation is not as stringent regulation as those for Nature 2000 sites, allowing for more flexibility in granting dispensation for specific planning and development projects. This flexibility can balance socio-economic goals with biodiversity goals but requires careful assessment to ensure biodiversity considerations are adequately addressed and potential negative impacts mitigated.

Unprotected species and areas have no specific legal protection but are still integral to biodiversity. While they may not be under immediate threat, they contribute to ecological networks and the overall health of ecosystems. Examples of unprotected habitats are urban green spaces, agricultural lands, roadside verges and grasslands, and species are e.g., bees and hares.

In CLDs, however, the level of protection is regarded as a dynamic factor that can change over time due to overall system behavior. This means that the level of protection can shift from unprotected to strongly protected and vice versa.

The effective implementation and use of SEA and EIA are vital for preserving flora, fauna, and biodiversity.

By distinguishing between nature types and species, and understanding the level of protection afforded to them, planners and environmental assessment professionals can make informed decisions that promote biodiversity. Distinguishing between protected and unprotected species and habitats ensures assessments and planning comprehensively cover all elements of biodiversity. This holistic approach is important for maintaining and supporting ecosystem services:

- Understanding the status of both protected and unprotected species and habitats allows for better identification and assessment of cumulative impacts. While highly protected areas are often the focus, both protected and unprotected areas can experience significant cumulative effects form multiple small-scale developments, which collectively can degrade biodiversity and ecosystem health.

- Incorporating both protected and unprotected species and habitats into EIAs and SEAs enables the development of more effective mitigation and enhancement strategies. It ensures that potential impacts on the entire ecosystem are considered, rather than focusing solely on highly protected areas. This includes e.g., creating buffer zones and enhancing connectivity between habitats.

- Recognizing the importance of unprotected species and habitats can contribute to broader biodiversity goals as unprotected areas often serve as important wildlife corridors or buffer zones that support protected areas.

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2.4 A broader perspective on Ecosystem Services

In section 2.1, different tools and approaches for assessing biodiversity in SEA and EIA are presented. One of these are Ecosystem Services (ESS), being "the benefits that people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005: 49). This includes provisioning, regulating, cultural and supporting services (Millennium Ecosystem Assessment, 2005) and represents diverse values of nature – which all need to be addressed in spatial planning processes (Laporta et al., 2023).

As presented, ESS can be a meaningful tool to be used in SEA and EIA practices. However, especially SEA can be instrumental in mainstreaming ESS into spatial planning and policy development. The BioValue 'Framework for integration of ES mapping and assessment in spatial planning decisions' (Laporta, 2023) determines the relevance of SEA to be 'very relevant' for up taking the outcomes of ES assessment, including: a) the identification of ecological state of ecosystems, b) the understanding of EC-ES relationships, c) the identification of trade-offs and synergies in ES supply and demand, and finally for d) identifying power relations in conflicting trade-offs (Laporta et al., 2023: 40).

Furthermore, the broad concept of environment in both SEA and EIA supports the holistic assessment, which aligns well with the broad and integrative nature of ESS. Since the processes of SEA and EIA typically involve extensive stakeholder engagement, they also provide an arena for identifying and valuing ESS.

By considering ESS, we broaden up the perspective beyond solely focusing on biodiversity values. Other values and ESSs are provided by a range of habitats and species. Expanding the focus from a distinction between protected and unprotected species and habitats to a more nuanced understanding in relation to the functionality and resilience of ecosystems, regardless of their protection status, the integration of ESS in SEA and EIA can recognize the interconnectedness of all habitats and the need to manage them holistically.

Section I: Biological Principles for planning and environmental assessment

In the context of BioValue, incorporating fundamental Biological Principles can enhance the effectiveness of all the instruments by providing a deeper understanding of which strategies and actions will effectively enhance biodiversity – and which potentially will lead to a decline. The selected Biological Principles for this approach are the area-species relationship and the source-sink dynamics. Both principles will be explored in detail in the following chapters.

For each principle, Causal-loop Diagrams (CLDs) will be presented to visually depict the dynamics involved. Subsequently, the implications for all three instruments within BioValue will be discussed.

3 Area of habitat: The species-area relationship

Increasing species richness (S) with increasing area of investigation (A) is one of the most fundamental 'laws' in ecology.

Dengler, 2009

The species-area relationship (SAR) describes the relationship between the area of habitat and the number of species it can support (see Figure 7). The larger an area the higher number of species due to greater habitat diversity and more resources (Petersen et al., 2024; Conor and McCoy, 2017).

Determining the optimal SAR is complex, as it among other factors varies across ecosystems and species (Drakare et al., 2006). An example of other determining factors is fragmentation. If an area is being fragmented, it likely necessitates a larger total area to ensure resilience of an ecosystem and a sustainable species population. Fragmentation will be explored further in chapter 10.

A species–area relationship is simply the observation that the number of biological species found in a region is a positive function of the area in the region.

Conor and McCoy, 2017.

In relation to transformative change, the principle is very important and can guide transformative change by underlining the importance of large areas. Further, SAR is relevant for the prediction of species loss and risk of local extinction (Drakare et al., 2017). As with the second Biological Principle, source-sink dynamics, SAR helps focusing on root causes to biodiversity loss.

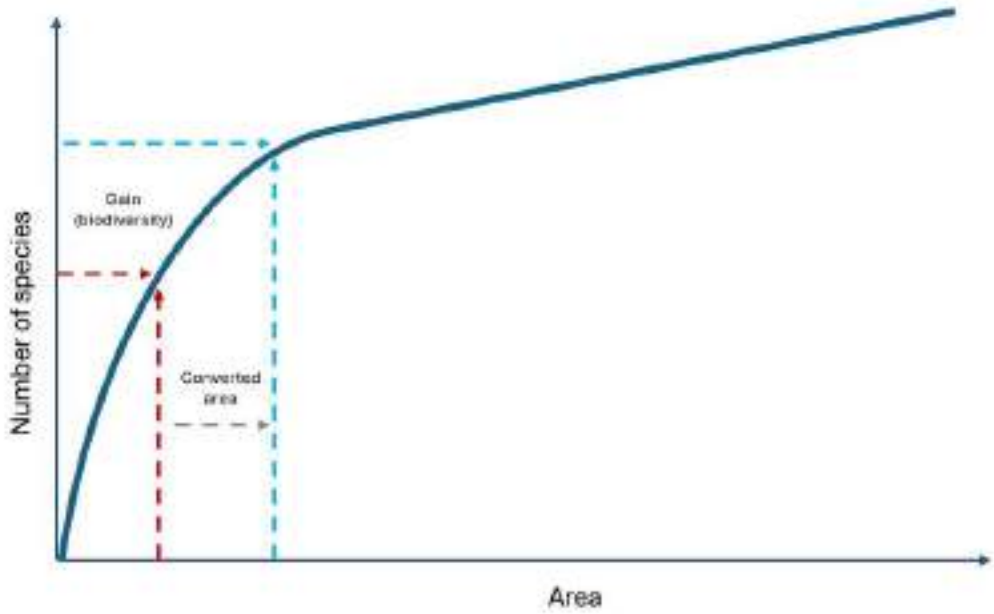

Figure 7: Species-area relationship, illustrating the basic biological correlation: number of species increased with the area of nature or the number of habitats. The larger area designated and converted to nature; the more species will benefit from the effort. (Figure is translated directly from Petersen et al., 2024, Figure 1)

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Biodiversity enhancement and the Habitat Directive
While the Minimum Viable Population (MVP) refers to the number of individuals required for a sufficiently high probability of population persistence or for sufficient retention of genetic variation for maintaining evolutionary potential." (EU Commission, 2017: 113), the Favorable Conservation Status (FCS), which is defined in the Article 1 of the Habitats Directive and can be described as "*a situation where a habitat type or species is prospering (in both quality and extent/population) and with good prospects to continue to do so in the future*" (EU Commission, 2017: 7) is not merely focusing on preventing extinction but on actively enhancing and sustaining a favorable status for habitats and species. So, favorable conditions that allow a population of species to prosper and exceed its MVP has the potential to contribute to the enhancement of biodiversity goals.

3.1 CLD for Biological Principle 1: The -species-area relationship

The CLD for Biological Principle 1 (BP1) demonstrates the SAR described above (see Figure 7). Two variables in this system form two of the three pillars of biodiversity (see Figure 11): the number of species and the persistence of ecosystems. The higher the number of species, the bigger their need for more habitats becomes, thus, overtime, leading to the occupation of more habitat by the different species. This reinforcing feedback is naturally balanced: When the area of habitat is sufficient, the needs of species for expanding their habitat becomes saturated.

The need for habitat is additionally driven by the individual species' need for a MVP to secure the persistence of the population. Thus, the need for habitat is dependent on the properties and needs for space of the individual species as well as the various population and ecological dynamics underlying the number of species.

The increase in the number of species, dependent on the dynamics of the first feedback, is also an endogenous factor of the second reinforcing loop, enabling the persistence of the ecosystems they live in, which has a positive effect on the overall quality of the area. An area of good quality attracts more species and vice versa; if the quality diminishes, so will the likelihood that species leave the area in seek of more suitable habitat. Here, the area mentioned throughout the CLD refers to the area as a nature type (wetlands, heath, forests, rivers, etc.) and to the area as a habitat for species (referring here to both flora and fauna).

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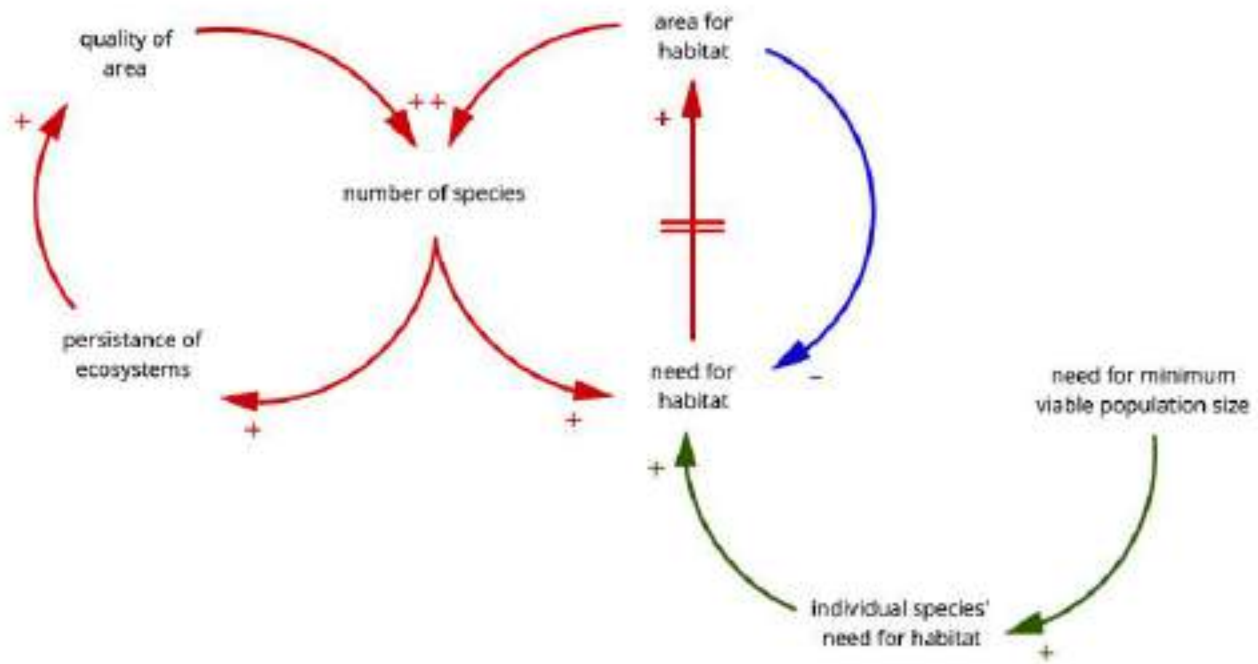

Figure 8: CLD for Biological Principle 1 (BP1) on the species-area relationship. (Source: Authors' model)

4 Connectivity: The source-sink dynamics

Local ecosystems are interconnected across space, continuously receiving and releasing matter and organisms through exchange mechanisms such as wind dispersal, water flow, animal movements and human activities (Polis et al., 2004). The interconnection can be explained through the source-sink dynamics.

‘Source’ refers to larger donor populations that are self-sustaining and capable of supplying surplus individuals to smaller recipient populations (sinks), which depend on individuals from outside to maintain their population levels (Petersen et al., 2024). The definition of a sink is “an area where factors are not sufficient for a species to carry out its life history” (Pulliam, 1988: 658)

“Animal and plant populations often occupy a variety of local areas and may experience different local birth and death rates in different areas. When this occurs, reproductive surpluses from productive source habitats may maintain populations in sink habitats, where local reproductive success fails to keep pace with local mortality.”

Pulliam, 1988: 660

The sink populations are thus dependent on the more productive source nearby, and without continuing immigration, the sink population will disappear (Pulliam, 1988). In Figure 9, Petersen and colleagues (2024) illustrate the source-sink dynamic and explain how increasing the natural habitat area of selected sinks (dotted red lines) can lead to a growing small-subpopulation with some becoming self-sustaining and capable of supplying surplus individuals to other areas (red arrows).

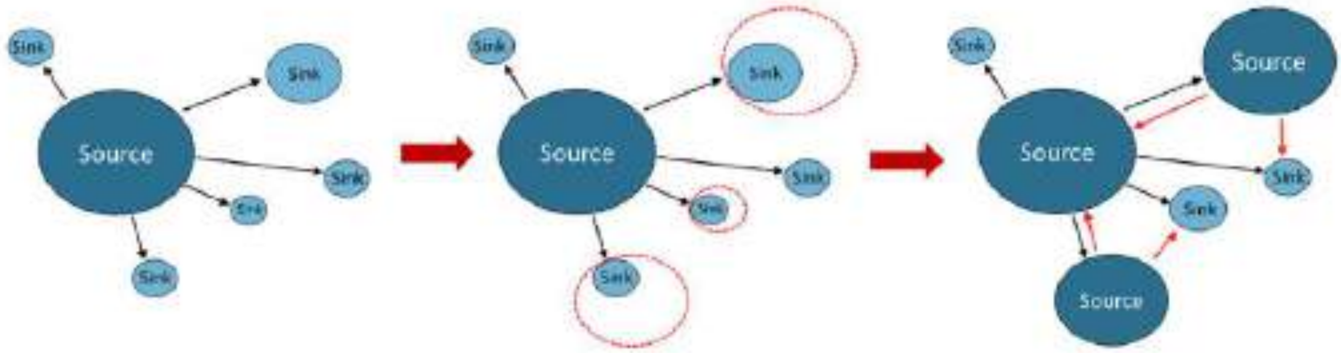

Figure 9 Meta populations and source-sink dynamic (Source: Adapted from Petersen et al., 2024, figure 2, page 14).

4.1 CLD for Biological Principle 2: The source-sink dynamics

The CLD for Biological Principle 2 (BP2) shows the reinforcing source-sink dynamics described above (see Figure 10). Firstly, the exchange of individuals (individual members of a certain species) is directly linked to the source (or donor) population of that species. Thus, individuals from a growing source population will spread and exchange, genetic information, and, over time (delay), enhance the existing sink populations. This means that a sink population, with some delay, can grow to become a source population itself. In combination, the source and the sink populations and the exchange of genetic information contribute to the persistence of the total population of that species, i.e. a metapopulation. When the metapopulation has reached a certain size, it can be self-sustaining.

The exchange of individuals is crucial to maintaining genetic diversity, one of the three pillars of biodiversity. It is driven by the number of habitats and the resulting connectivity. The closer the habitats, the more likely an exchange between them can happen according to the species' ability to spread. The development of the source-sink dynamics depends on the quality of the drivers. If the number of habitats is numerous and they are well-connected, population sizes will thrive, and sinks will become sources. If either of the drivers are negative (meaning a low number of habitats or habitats with little connectivity to one another) then this is likely to result in an exponential decline of source and sink populations, and with local extinction as endpoint, resulting in a loss of genetic diversity.

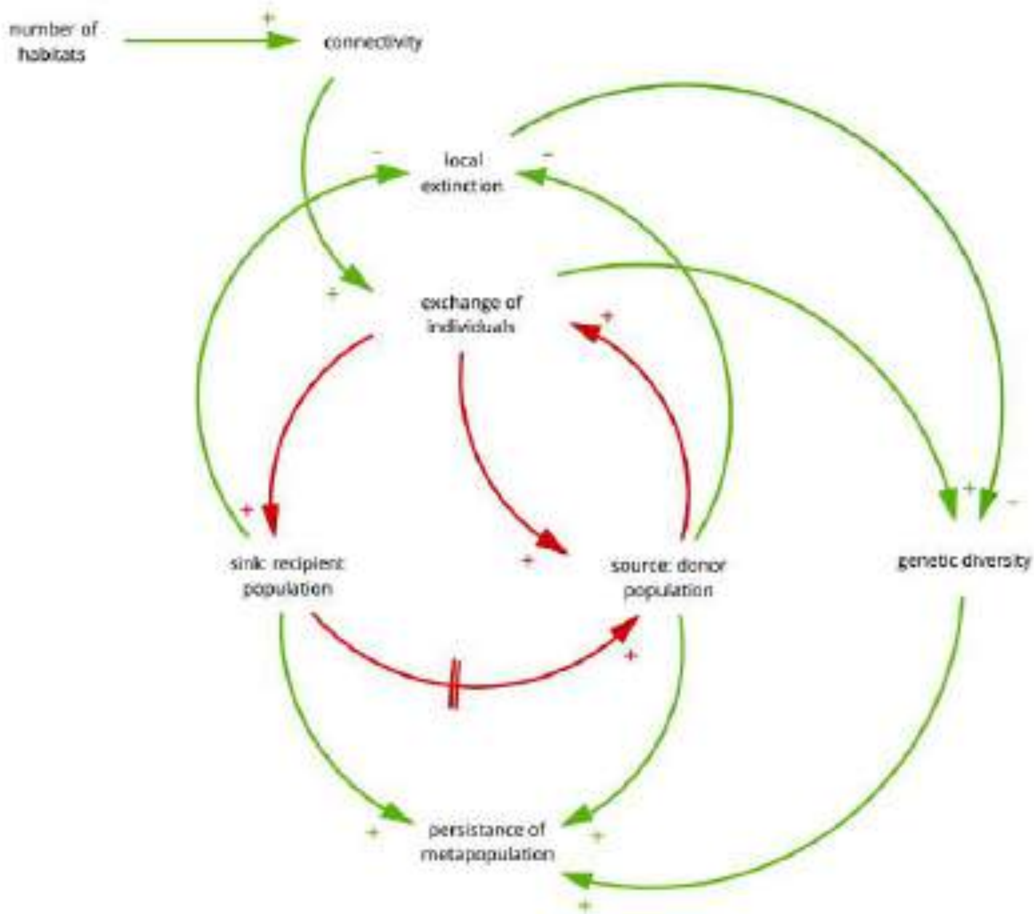

Figure 10: CLD for Biological Principle 2 on source-sink dynamics. (Source: Authors' model).

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5 CLD for Biological Principle 1 and 2 combined

Combining the CLDs for the subsystems of BP1 and BP2 demonstrates the interlinkages and interdependencies (dashed lines) between the SAR and the source-sink dynamics The system's complexity increases, opening up for new pathways and feedback loops (in total 16 reinforcing, 14 balancing, see Annex II for complete list of feedback loops). This means that anything happening in one subsystem will affect the other subsystem in some way. The ideal situation is a system in balance. This means that the reinforcing loops are kept in check by the balancing loops.

The new pathways link various variables in the system and new dynamics arise. The two reinforcements in BP1 remain, and the balancing loop now additionally includes the number of habitats. The quality of the area in combination with the area for habitat determines the resulting number of habitats, that contribute to the persistence of ecosystems.

BP1 becomes a driver for the entire system of BP2 through the impact of the number of habitats on connectivity, which also means that any changes that occur in BP1 impact the dynamics in BP2. Further, the persistence of metapopulations resulting from BP2 are now contributing to the number of species, thus forming various reinforcing loops connecting both subsystems, following the described pathways of the source sink dynamics, but also now including genetic diversity, which previously was merely a result, in the dynamics of the system.

The balancing behavior of the system is also enhanced. Any loop involving one of the links between genetic diversity and the need for genetic diversity, sources and sinks counteracting local extinction as well as the needs for habitat being affected by the number of habitats has a balancing effect on the entire system. Local extinction in BP2, links to the need for the MVP in BP1 and associated pathways through the entire system. Reaching the MVP becomes a driver for the species' need for more habitat in BP1. This highlights the indirect importance of population sizes, which, depending on the individual species' needs and abilities, can differ as some populations can survive through mutation or adaptation as long as the minimum viable population size is maintained, instead of the exchange of individuals leading to genetic diversity. Lastly, the greater the persistence of the metapopulation (meaning that the species is self-sustaining), the greater the number of species which then influences the persistence of the ecosystems and the need for habitat.

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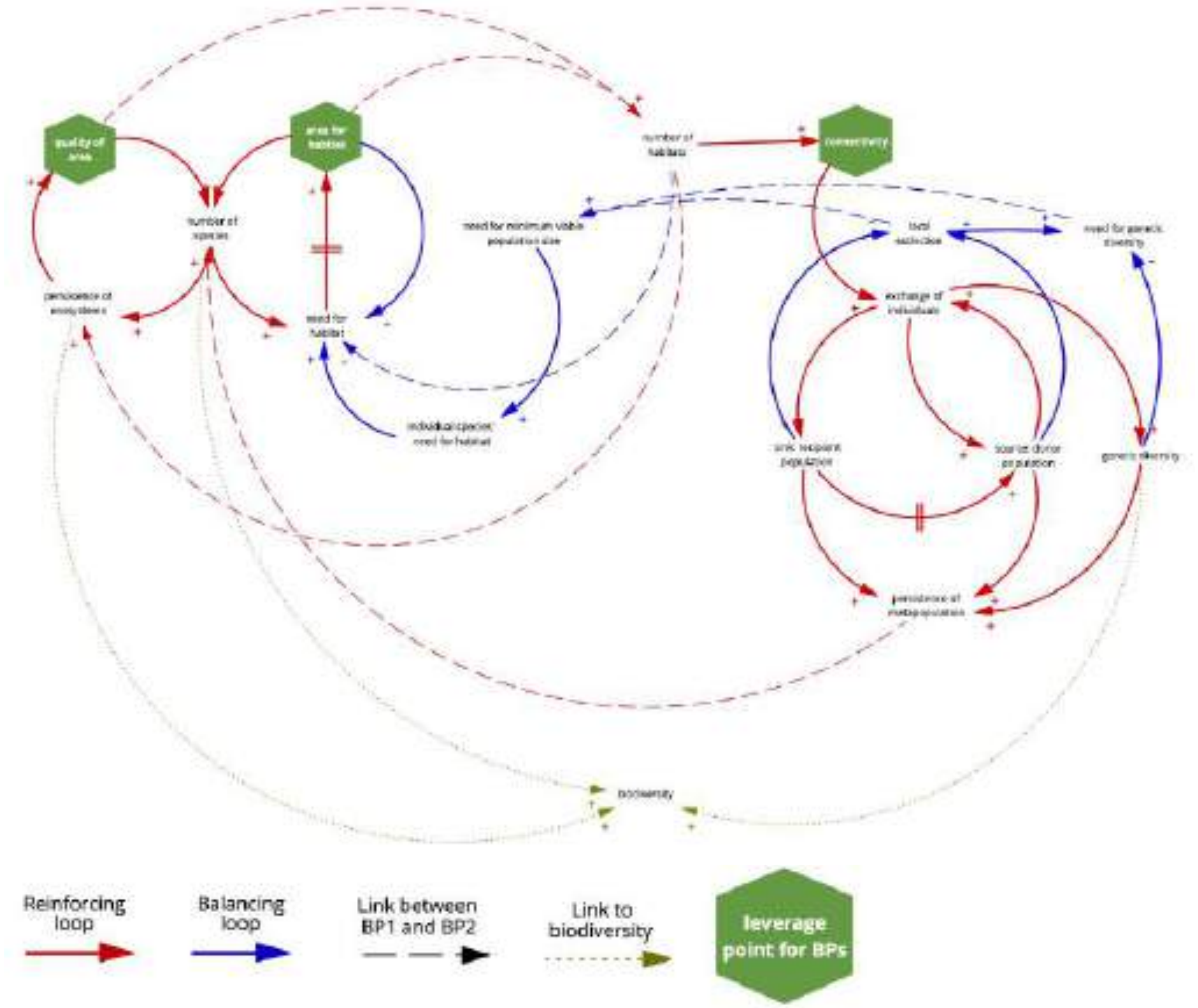

Figure 11: The CLD on combining Biological Principle 1 and Biological Principle 2 including the emphasis of leverage points, variables with importance to spatial planning. (Source: Authors' model)

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6 Implications of Biological Principles and leverage points for environmental assessment in spatial planning processes

6.1 Opportunities arising from the Biological Principles

The integration of Biological Principles such as the species-area relationship (SAR) and source-sink dynamics into SEA and EIA processes is crucial for enhancing the effectiveness of spatial planning in achieving biodiversity conservation, ecosystem management, and sustainable development goals.

When viewed through the lens of systems thinking, these principles offer a comprehensive approach to understanding and managing the complex interdependencies within ecosystems, as well as the broader spatial planning context in which these systems operate.

The species-area relationship (SAR) and source-sink dynamics are as described two foundational principles that can greatly inform the environmental assessment process, enhancing its effectiveness as an instrument to support transformative change in spatial planning towards protecting and enhancing biodiversity.

The SAR emphasizes that large, protected areas can support more species, underscoring the importance of creating expansive natural areas in spatial planning and management for biodiversity conservation. This principle informs decision-makers about the benefit of consolidating habitats into larger, contiguous areas to maximize species protection and ecosystem resilience.

Similarly, source-sink dynamics are inherently linked to spatial considerations, focusing on the distribution of habitats and their connectivity. Source habitats, which have a surplus of resources and support population growth, are critical for sustaining nearby sink habitats that rely on incoming individuals to maintain their populations. Spatial planning plays a pivotal role in either maintaining or enhancing these vital connections.

Integrating these principles into environmental assessment processes helps identify critical habitats and maintain spatial connectivity. It enables the identification of opportunities for biodiversity protection and enhancement, assessment of impacts on biodiversity and ecosystem services, and proposal of mitigation and enhancement measures. Furthermore, it involves stakeholders and incorporates monitoring for adaptive management. These strategies collectively guide land-use decisions towards ecological priorities.

6.2 Opportunities by utilizing leverage points

The Biological Principles and the interconnections between them clarify approaches to enhancing biodiversity. Ensuring that these approaches are used is where spatial planning plays a crucial role.

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Identifying and utilizing leverage points within these systems can enhance the outcomes of spatial planning processes.

Mapping the system of BP1 and BP2 allows for identifying the variables in the system that are most influential. These are elements that are highly connected or have a significant impact on the system's dynamics, i.e. determining the system's behavior. In the context of spatial planning, it is also relevant whether or not the decision maker has the mandate to apply change to that particular variable or system structure.

More specifically, spatial planning has the opportunity to i. plan for the improved quality of a nature area, including the habitats that reside there, ii. designate areas for nature, thereby ensuring that needs of habitats for species are met, and iii. plan for the connectivity of existing habitats. These three 'entrances' for spatial planning in the fundamental Biological Principles are also shown in the CLD as green hexagons.

Although the choice of leverage points in the combined system of the Biological Principles can appear intuitive and no news for the experienced planner, the systems approach adds some valuable insights.

All three variables are highly connected within the system with the area for habitat being involved in six reinforcing feedback loops and 16 (all) balancing feedback loops. Any change in the area for habitat will therefore ripple through the system and potentially turn the dynamics of the overall system to a negative outcome for biodiversity. The same applies to the quality of area, involved in seven reinforcing and eight balancing loops as well as connectivity, involved in eight reinforcing and 14 balancing loops.

In addition, all three leverage points are involved in feedback loops with delays. This means, that the dynamics of the delayed feedback moves slower than the rest of the system, or that the effect from one variable causing a change in the other variable takes longer time in relation to the dynamics of other feedback loops. In the Biological Principles, these dynamics involve the transformation from sink to source populations as well as the expansion of area for habitat.

A change in any one of these leverage points will affect all other variables in the system. Even if there is no data or detailed information on the single variables available at certain stages of the planning process, the awareness of the existence of the numerous feedback loops, the interconnectivity and complexity of the system may assist in precautionary decision making.

Meadows (1997) identified 12 places to intervene in a system, the identified leverage points are regarded to play a crucial role as stabilizing buffers, as part of the overall system structure including the length of delays relative to the rate of system change, in the strength of the balancing feedback loops relative to the impacts they are trying to correct against as well as the gain around positive feedback loops.

When adding any of the cases explored in the remainder of this report to the Biological Principles (see Section II), this awareness and the understanding of the interconnectivity of leverage points allows for a deeper analysis and evaluation of the planned change, especially when the proposed change adds further loops to the leverage points. In order to simplify the implementation of Biological Principles and leverage points to case studies, a simplified version of the combined systems is applied (see Figure 12).

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It may be noted that by adding specific cases to the Biological Principles (see Section II), and thereby expanding the system boundaries, a greater number of opportunities for intervening in the system are most likely to occur. These additional and even stronger leverage points (Meadows, 1997) can change the structure of information flows, e.g., amongst stakeholders and decision makers, changing certain rules of the system, e.g. through incentives or constraints, as well as identifying where or by whom the power lies to add, change or evolve system structures. The most powerful leverage points are to be found when system boundaries are broadened even further, including the dynamics influencing the goals of the system, the mindset or paradigm out of which the system arises, including its goals, structure, rules, delays, parameters as well as the power to transcend paradigms.

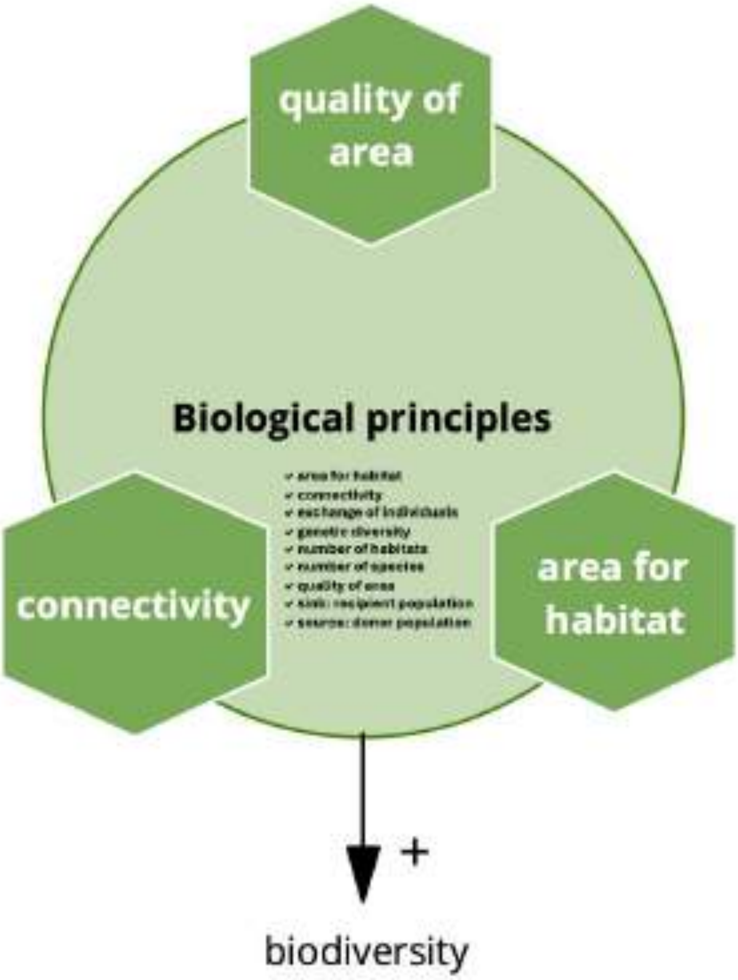

Figure 12: Biological Principles summarized with check list for planners and EA practitioners. (Source: Authors' model).

Figure 13 highlights some examples, showing how applying SAR and focusing on source sink dynamics within the Biological Principles can enhance biodiversity outcomes through environmental assessments and strategic planning. This approach includes identifying critical habitats, maintaining connectivity, engaging stakeholders, considering financial and economic mechanisms, and implementing long-term adaptive management measures. It is important to underline that these are just examples, and they will be further elaborated with concrete cases in Section II. This deeper exploration will illustrate how SAR and source-dynamics are applied in real-world scenarios to guide land-use decisions, align planning and policy making with ecological priorities, and strategically deploy a range of incentives and measures for biodiversity.

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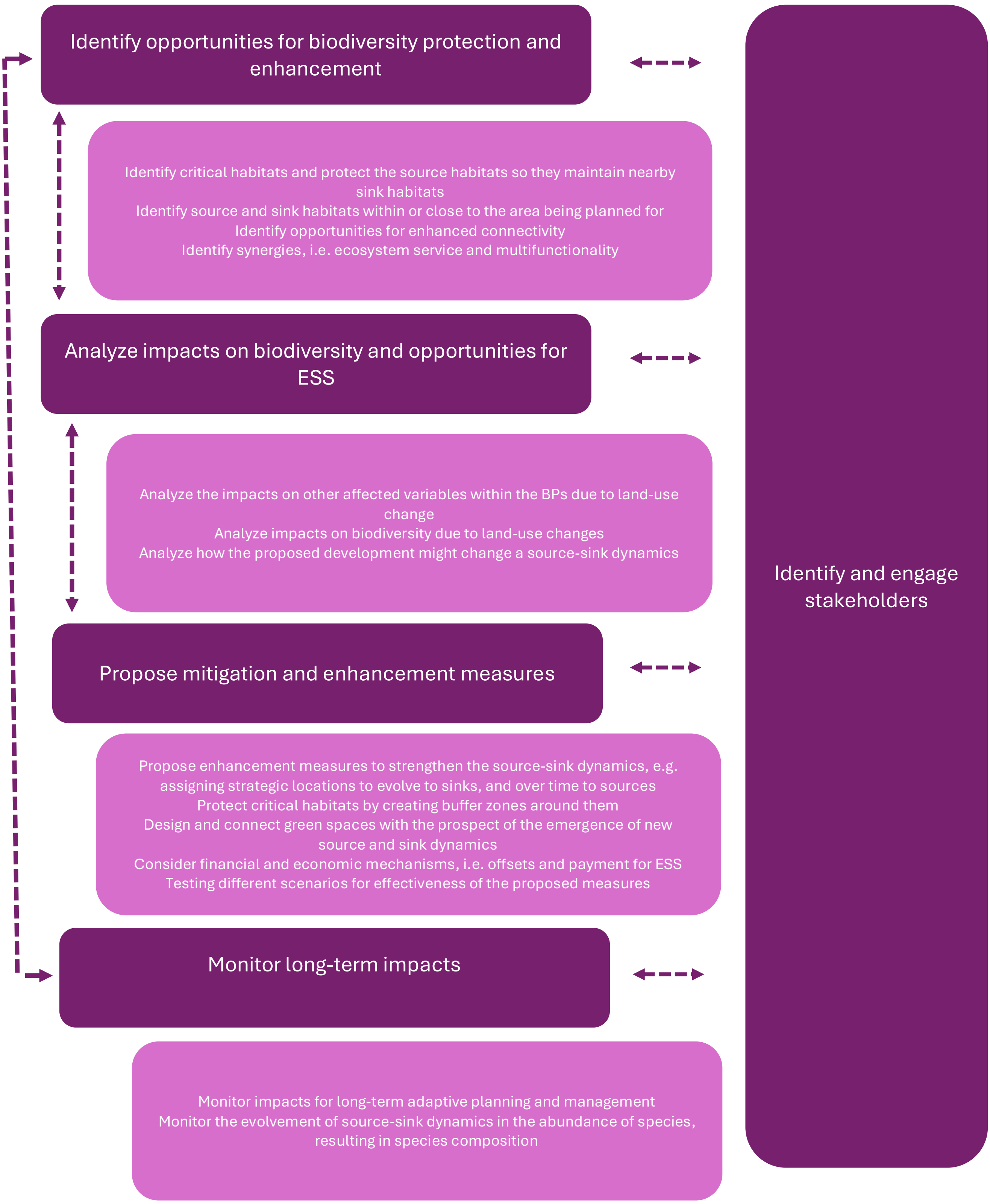

Figure 13: Examples of roles for EA in spatial planning processes to support the leverage points arising from the Biological Principles. (Source: Authors' model.).

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The following Figure 14 illustrates more closely how the principles can be integrated into the environmental assessment process to support a more proactive role in biodiversity protection and enhancement during project and plan development.

This integration allows environmental assessments, such as SEA and EIA, to move beyond their traditional more reactive function, to playing a more strategic and influential role in proactively shaping projects and planning from the very early stages.

The figure outlines the environmental assessment process phases, from the initial project design or plan development through screening, scoping, assessment, mitigation, and monitoring. At the earliest phase, the principles can be pivotal in identifying opportunities for biodiversity protection and enhancement. For example, recognizing the need to maintain larger contiguous habitats (guided by SAR) or ensuring connectivity between source and sink areas can shape project and plan design at the outset. This early consideration enables planners to embed ecological priorities into their proposals, making biodiversity enhancement a core component rather than an afterthought.

By identifying these principles during the identification of opportunities, the environmental assessment process can inform decision-making at the very early phases, ensuring that projects and plans are aligned with ecological principles from the start. This approach ensures that SEA and EIA contribute meaningfully to the development process, guiding planners towards decisions that protect critical habitats, enhance connectivity, and promote overall biodiversity outcomes.

Thus, as shown in Figure 14, integrating the principles into environmental assessments fosters a more proactive, strategic approach by informing and influencing planning and decision-making.

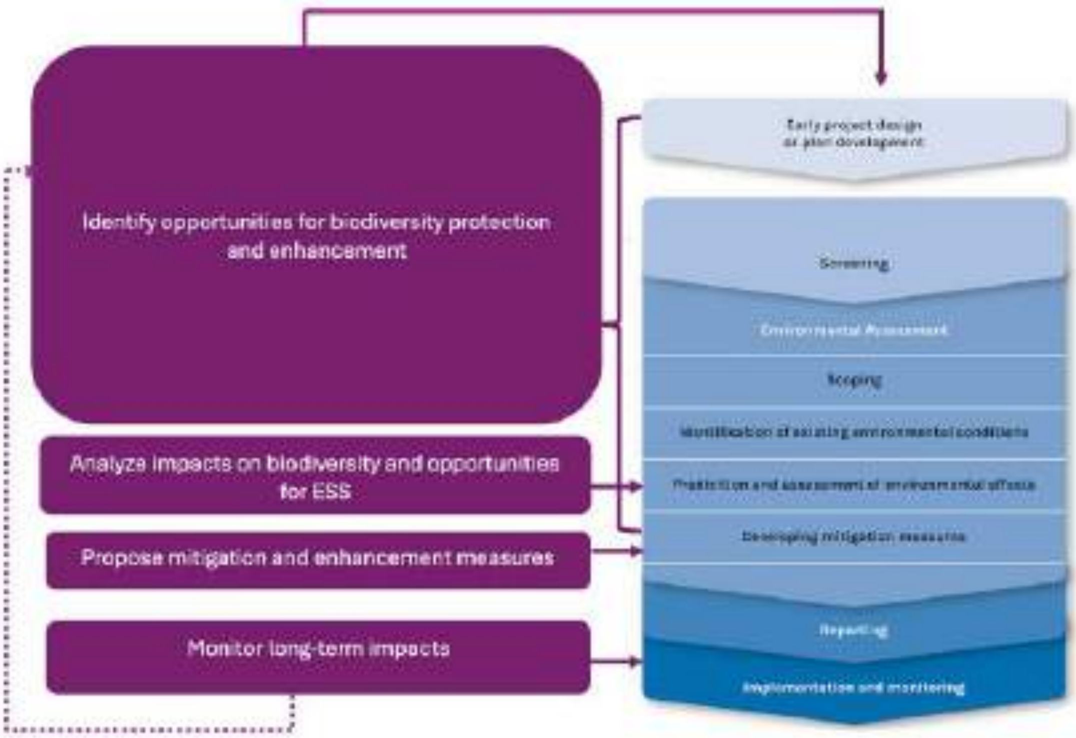

Figure 14: Integration of EA in spatial planning processes to utilize the leverage points from the Biological Principles. (Source: Authors' model and DCEA, AAU 2021 (The EIA/SEA process)).

Section II: Exemplary planning cases and their corresponding CLDs

The primary causes of biodiversity loss are due to human activities and are significantly related to land use and land-use changes (Foley et al., 2005; IPBES, 2019), and thus directly linked to how a society plans for and manages its land and resources.

In this section II, four planning cases will be unfolded and corresponding CLDs presented. The planning cases serve as practical examples to illustrate the relationship between spatial planning, environmental assessment and financial and economic instruments related to biodiversity outcomes.

The selection criteria, which are unfolded in chapter 13 regarding the methodology, provide cases for four CLDs that reflect diverse and commonly relevant spatial planning situations and their impacts on biodiversity. The cases selected are rooted in the insights gained from analyzing causalities in SEA and EIA reports concerned with spatial planning and infrastructure development projects. By examining these reports, the project team was able to pinpoint key areas where biodiversity is most at risk due to specific land-use changes, and where interventions could potentially have the most significant impact. This analytical process also considers broader development tendencies in Europe that influence biodiversity, such as urban expansion, agricultural practices, push for renewable energy production, and expansion of infrastructure. These trends are mirrored in the selected cases, making them particularly relevant for understanding how spatial planning decisions can enhance biodiversity, mitigate or intensify biodiversity loss.

The selected cases are therefore illustrative of common scenarios that planners and policy makers face across Europe, making them highly relevant for broader applications beyond the specific contexts of the BioValue project. They further directly address some of the bottlenecks identified in BioValue, which concerns the cross-sectoral integration of critical areas such as energy and infrastructure:

“Spatial planners and ecologists should be more involved in planning urban expansion studies, energy infrastructure, solar farms, wind farms, and urban networks. This integration would help to incorporate the concept of green infrastructure right from the start in broader planning scales, avoiding fragmentation of habitats and landscape degradation.” (Hoyos-Rojas et al., 2023: 20).

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7 Explanation of the four planning cases and the contextual application in BioValue arenas

Three out of the four CLDs altogether reflect primary land-use related causes of biodiversity loss, which are:

1. *Conversion of agricultural areas*
   It is well established that agricultural land uses have significant impacts upon terrestrial ecosystems (IPBES, 2019). Changing the agricultural land cover by e.g. reverting to forest or transforming into urban development influences biodiversity opportunities. The choice of a photo-voltaic park as an example highlights the conflict between climate mitigation efforts (such as increasing renewable energy capacity) and biodiversity conservation. The SEA and EIA analyses pointed to this land-use change as a common and impactful scenario, especially in regions where agricultural land is under pressure for alternative uses.

2. *Habitat conversion*
   Converting habitats to other human uses can lead to irreversible loss of habitat and accompanied by fragmentation of remaining habitat (Hogue and Breon, 2022). This is illustrated through the case of converting protected areas to urban uses. This case was chosen to reflect the irreversible nature of such conversions and their potential to fragment ecosystems. The SEA and EIA reports identified urban expansion as a threat to biodiversity, making this case relevant for areas experiencing increasing urbanization.

3. *Habitat fragmentation*
   Habitat fragmentation has the effects of “increase in the number of patches, decrease in patch sizes, and increase in isolation of patches” (Fahrig, 2003: 492). This land-use change is illustrated through the case of fragmentation of habitats due to linear infrastructure such as road construction. The case was selected because it represents a widespread and ongoing issue across Europe. The choice reflects the insights gained from the analysis in SEA and EIA reports, where linear infrastructure often emerges as a key driver of habitat fragmentation, leading to biodiversity loss.

The fourth CLD reflects the case of the:

4. *New habitat development and carbon sequestration*
   This case illustrates the positive impacts of creating new habitats. Establishing new habitats plays an important role in both mitigating loss of habitats and enhancing biodiversity. The selection of afforestation was informed by the need to explore solutions that can offset biodiversity loss. It also ties into broader European policy goals around carbon sequestration and climate change mitigation, demonstrating the potential for co-benefits in spatial planning decisions.

7.1 Contextual application in BioValue arenas

The four planning cases selected are connected to the specific contexts and challenges faced by the three BioValue arenas – Mafra Municipality (Portugal), Trento city and Fersina River (Italy), and the

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Mecklenburg-Vorpommern (Germany). The four cases provide a flexible framework that can be adapted to various contexts within the BioValue arenas.

Mafra Municipality

For Mafra Municipality arena, the primary focus is on safeguarding natural values and biodiversity in the face of increased tourism pressure. Examples of relevant cases are:

- *Conversion of agricultural areas*. Mafra faces significant pressures due to tourism, which can lead to the conversion of agricultural land into urban or recreational uses. The principles demonstrated in the case of agricultural land conversion to PV parks can be applied here, albeit with different end uses, to understand the impacts on biodiversity and potential conflicts between tourism, food security, and biodiversity preservation.
- *Habitat conversion*. As tourism demands grow, there is a risk of converting protected or natural areas into tourist infrastructure. The case of habitat conversion can help assess the potential biodiversity loss and guide spatial planning to balance development with conversion.
- *Habitat fragmentation*. Increased tourism can necessitate the development of new infrastructure, such as roads, hotels and recreational facilities. The case of habitat fragmentation can help stakeholders understand the potential impacts of such developments on local ecosystems, mitigate the impacts, and support long-term planning that aligns with sustainable tourism goals.

Trento and the Fersina River

The Italian arena focus primarily on incorporating biodiversity into the co-management of urban and natural areas, particularly focusing on fluvial ecosystems. Examples of case relevance is:

- *Habitat fragmentation*. The planned development around the Fersina River, including the creation of green corridors and fluvial parks, can benefit from insights provided by the habitat fragmentation case. This can guide efforts to enhance ecological connectivity and reduce habitat loss due to urbanization and infrastructure.
- *Habitat conversion*. As the Fersina arena seeks to balance urban growth with ecological preservation, the habitat conversion case can provide a framework for evaluating the impacts of transforming natural areas into urban spaces and help develop strategies.
-

Mecklenburg-Vorpommern

This arena focuses primarily on peatland rewetting as part of climate protection and biodiversity enhancement strategies, which supplement the earlier emphasis on reforestation. Relevant cases are especially:

- *New habitat development*. The focus on rewetting peatlands aligns well with the case on new habitat development. This case helps stakeholders understand the ecological and biodiversity benefits of this restoration efforts, as well as the potential for carbon sequestration, contributing to climate goals.
- *Conversion of agricultural areas*. The challenges of converting agricultural land into natural habitat or wetlands can be analyzed using this case, which Is relevant as Mecklenburg-Vorpommern navigates the complexities of land-use change in the context of climate mitigation. Applying the specific area use after conversion, PV parks, might also apply to the rewetting projects in Mecklenburg-Vorpommern in the scenario of co-locating PV installations with rewetting projects and hereby create synergies.

The specific recommendations for each BioValue arena, derived from the case-specific CLDs and the Biological Principles, will be further elaborated in chapter 12. These recommendations are intended to offer preliminary, tailored strategies for applying the lessons learned from each case to the unique contexts of Mafra, Trento, and Mecklenburg-Vorpommern.

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8 Conversion of agricultural areas

Agriculture has multifaceted and profound impacts on biodiversity. The impacts encompass especially habitat loss due to conversion of natural habitats, use of pesticides and fertilizers, degradation of soils, water use and pollution (Natural Academy of Sciences, 2021). Agriculture furthermore represents a key pathway for the intentional or accidental introduction of invasive species and is at the same time impacted (Montagnani et al., 2022).

Under a business-as-usual scenario, land devoted to crops is expected to expand in many parts of the world, causing increased land clearing, greenhouse gas emissions, and extinction.

National Academy of Sciences. 2021: 17

While converting agricultural land for more urban purposes raise concerns about potential biodiversity loss, it can also lead to positive biodiversity outcomes, particularly by avoiding the abovementioned negative impacts associated with ongoing intensive agricultural practices. However, it is essential to balance these local and regional positive biodiversity impacts with potential negative impacts on a global scale. As the global population continues to rise, the demand for food increases – reflecting the indirect driver of demographic changes. This demand of "growing more crops for consumption by both people and livestock will require increasing yields on existing land or converting more wildland cropland." (Natural Academy of Sciences, 2021: 14). Both scenarios have implications for biodiversity– although different types and in different regions. The cropland intensification and the shifting pressure due to land-use change in another geography (through e.g. deforestation) is defined as indirect land-use change (iLUC) being "the upstream life cycle consequences of the land use", while the direct land-use changes (dLUC) are the "changes that occur on the same land as the land use" (Schmidt et al., 2015: 230). Both are illustrated in Figure 15.

Conversion of agricultural land can thus lead to an enhancement in local and regional biodiversity outcome, such as habitat restoration and soil conservation, but at the same time indirectly contribute to a global biodiversity loss by shifting agricultural pressure elsewhere. This is especially critical in the case of deforestation in areas with high biodiversity values (van Vliet, 2019).

An important role for spatial planning is to prioritize conversion of low-value agricultural lands, such as marginal or degraded agricultural lands due to the lower productivity and biodiversity values. Another strategy is to utilize brownfield or previously developed land for urban purposes.

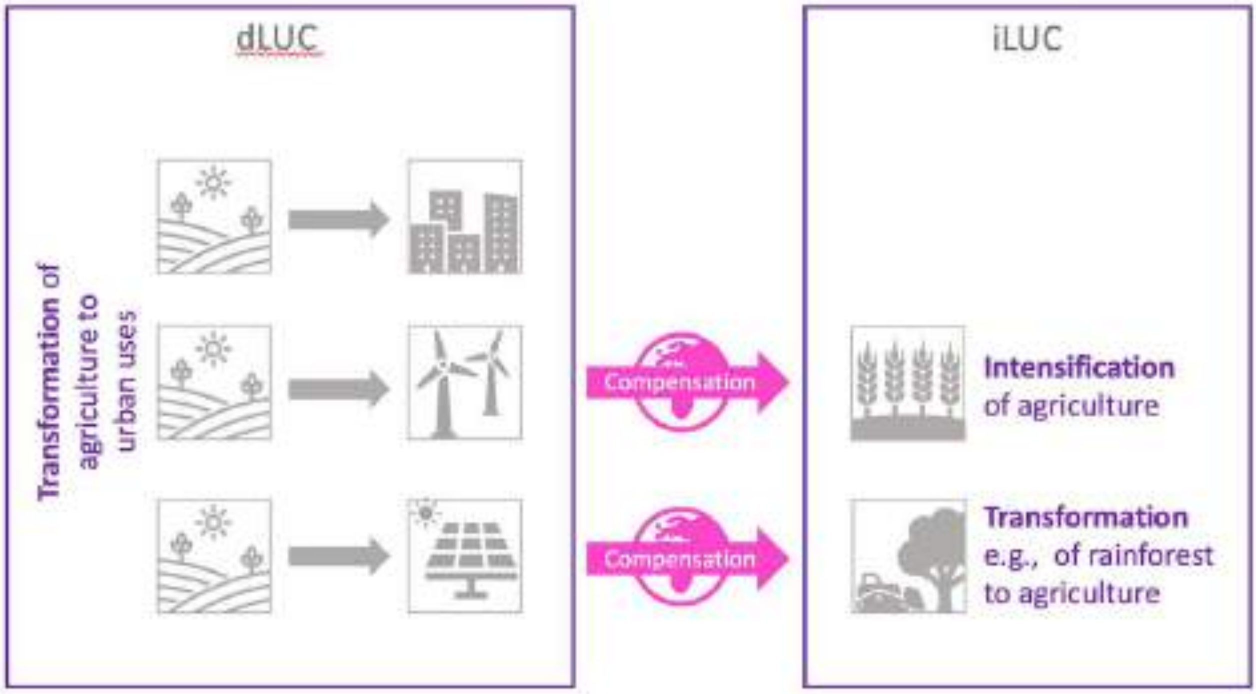

Figure 15: Illustration of the direct land-use changes (dLUC) and indirect land-use changes (iLUC) related to the transformation of agricultural areas (Source: DCEA, AAU).

8.1 Planning case: Converting agricultural land to photo-voltaic parks

The planning and establishment of photo-voltaic (PV) parks in Europe are increasingly becoming a focal point of land-use policy, reflecting broader trends and challenges.

Large PV parks are being developed across the European Member States, a trend projected to continue as part of the push towards renewable energy (SolarPower Europe, 2023). However, these developments, which take up large acreage and often takes place on agricultural land, are intensifying global competition for land (van de Ven et al., 2021). This intensification poses challenges to biodiversity conservation, given the space constraints that are already a critical issue for many species (as illustrated in BP1 on area-species ratio).

Situating expansion of renewable energy in a broader governance and planning perspective
The competition for land is further complicated by various overlapping land-use policies in Europe. For example, the European Green, aimed at achieving climate-neutrality by 2050, and the EU Biodiversity Strategy for 2030, which sets ambitious targets for protecting 30% of Europe's land and restoring degraded ecosystems like peatlands, potentially conflict with the demands for renewable energy infrastructure, such as PV parks.

Further, there is a need for retaining or intensifying agricultural land for a growing population, which is supported by the EU's "Roadmap for a Resource-efficient Europe". The policy emphasizes the sustainable use of natural resources, including soil. It aims to protect and enhance soil quality, recognizing that soul is a finite and vulnerable resource, and needed for future agricultural productivity.

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Balancing these competing demands requires careful spatial planning and a strong policy alignment, while carefully managing the conversion of agricultural land to ensure that Europe's resources are sustainably utilized.

The conversion of agricultural land for PV parks in Europe has important governance and institutional dimensions (see Figure 15). For instance, the planning process for PV parks is in Denmark frequently driven by project-level interests, which can lead to a situation where decisions are made on short-term economic or political considerations rather than long-term sustainable land management. This process is seen to shortcut comprehensive, proactive spatial planning and environmental assessments that could identify the best locations of PV parks in ways that minimize their impacts on biodiversity. Without a holistic, coordinated approach, the location of PV parks can contribute to habitat fragmentation and loss.

Specifically, for the BioValue arena in Germany, which focuses on rewetting peatlands, exemplifies this tension between restoration efforts, the need to expand renewable energy sources and protecting good soils for agricultural production. Rewetting peatlands, from agricultural productive land, contributes to carbon sequestration and biodiversity, aligning with the Biodiversity Strategy. However, it also potentially competes with the space needed for PV parks.

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8.2 CLD for the conversion of agricultural land

The conversion of agricultural land has the potential to impact the leverage points identified in the Biological Principles, and thereby promote the enhancement of biodiversity through spatial planning that encourages land-use change to other purposes than agriculture. **Fejl! Henvisningskilde ikke fundet.** depicts the system in which land is converted from agriculture to a PV park, outlining the spatial planning, environmental and governance factors influencing such system. Although this case describes the construction of PV parks, it applies to any new spatial planning that requires the conversion of area to accompany new development purposes.

This example of constructing PV parks consists of four 'modules'; 1. the direct environmental impacts from planning for the conversion of agricultural land (blue arrows), 2. the direct impacts from the construction and operation of the PV parks (green arrows), 3. the direct impacts of eco-centric planning and management (yellow arrows), 4. the indirect impacts from changes in mindsets on a governance levels (purple arrows), and 5. the indirect impacts from the designation of areas for certain land-uses as opposed to others (teal arrows).

The leverage points stemming from the Biological Principles, mitigation measures, and additional case specific leverage points identified for spatial planning and governance have been outlined in bold in the text below.

1. If taking the case of PV parks, prioritization of renewable energy policies leads to the need for more area for constructing PV parks. Choosing to convert agricultural land to meet this demand decreases the area for agriculture, while increasing the area for PV parks. By decreasing the area for agriculture, CO_2 emissions and pollution are also decreased, which in turn increases the **quality of natural areas**, which is identified as a leverage point for promoting the Biological Principles. Decreasing the area for agriculture improves hydrological conditions as does minimizing pollution from agriculture, which in turn improves the **quality of natural areas**. Pollution impacts the functionality of agricultural areas, decreasing the area for agricultural purposes overtime.

2. Renewable energy policies promote the construction of PV parks, resulting in their increased operation. The operation of PV parks promotes renewable sources of energy, effectively decreasing CO_2 emissions (a primary reason for the push for renewable energies and the prioritization of the policies), which then improves the **quality of natural areas**. Operating PV parks also increases the risk of collision of fauna with the established PVs, resulting in the death of individuals, weakening the persistence of local metapopulations of affected species. The persistence of metapopulations is an embedded part of the systems for Biological Principles, and through the biological systems described in Section I, effectively impacts the biological leverage points: **quality of natural areas**, **areas for habitat**, and **connectivity**. Enhancement and mitigation measures can be put in place to minimize and/or enhance conditions for the biological leverage points. A **fence around the PV park** can minimize the risk of collision, but also reduces the **connectivity** of habitats by obstructing the free travel of species between areas. Conversely, if constructing a **living fence**, it is possible to enhances **connectivity** (note: only for species able to travel along or across the **living fence**) while still reducing the risk of collision, making it a better alternative if seeking to enhance biodiversity. Establishing a **distance (buffer zone) between PV parks** and the **area for habitat** is also a measure for minimizing the risk of collision with PVs.

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3. **Eco-centric planning and management** of the PV parks can help contribute to improving the **quality of the area**, which increases the number of species and effectively biodiversity through the system of the Biological Principles. An example of this could be **planting local vegetation** in the area occupied by the PV parks.

4. Improving biodiversity through the Biological Principles has societal influences, supporting a more **eco-centric mindset in decision-making**. Overtime, this **eco-centric mindset** encourages the stronger protection of more area through the interest in protecting and conserving more natural areas. The level of protection of habitats and natural areas ranges from unprotected to strongly protected, which is determined through legislation and has consequences for what kind of area can be converted and what it can be converted to. The stronger the level of protection for a given area, the greater the overall **area for habitat** is, as a stronger protection advocates for the preservation of areas and ensures that the area cannot be converted for other purposes. Moreover, the stronger the protection, the greater the **quality of the natural area**, as strongly protected areas are those with rich opportunities for biodiversity and are natural areas with limited interference from external factors. A stronger level of protection decreases total area for agriculture. Lastly, an **eco-centric mindset in decision-making** encourages more **eco-centric planning and management**, which further improves **quality of the area**.

5. Due to the limited space for new development, areas, at least in a Danish context, function as a natural resource as the designation of land-use on these areas have impacts on the availability of land for other purposes. Considering the green transition, there is an increased pressure on accelerating renewable energies, and in many cases, **renewable energy policies are prioritized** in spatial planning. In Denmark, agricultural areas are often assigned to accommodate these renewable energy policies, meaning that the **decision to convert agricultural land** increases. As agricultural areas are converted (in this case, to PV parks), the total area of agriculture is decreased, meaning that there is less agricultural area available for other purposes than PV. This consequently reinforces the competition for area for meeting different needs. Adopting **mixed land-use**, designating multiple functions to one area, leaves more area for agriculture for either preserving its agricultural function (through i.e. agrivoltaics) or for other purposes. **Mixed land-use** can thereby enhance the conditions for land-use by mediating the competition for areas. Lastly, if recognizing the need to preserve some agricultural areas for the purpose of food production and through that, prioritizing the **preservation of high-quality soil**, there would be a decrease in the decision to convert agricultural area.

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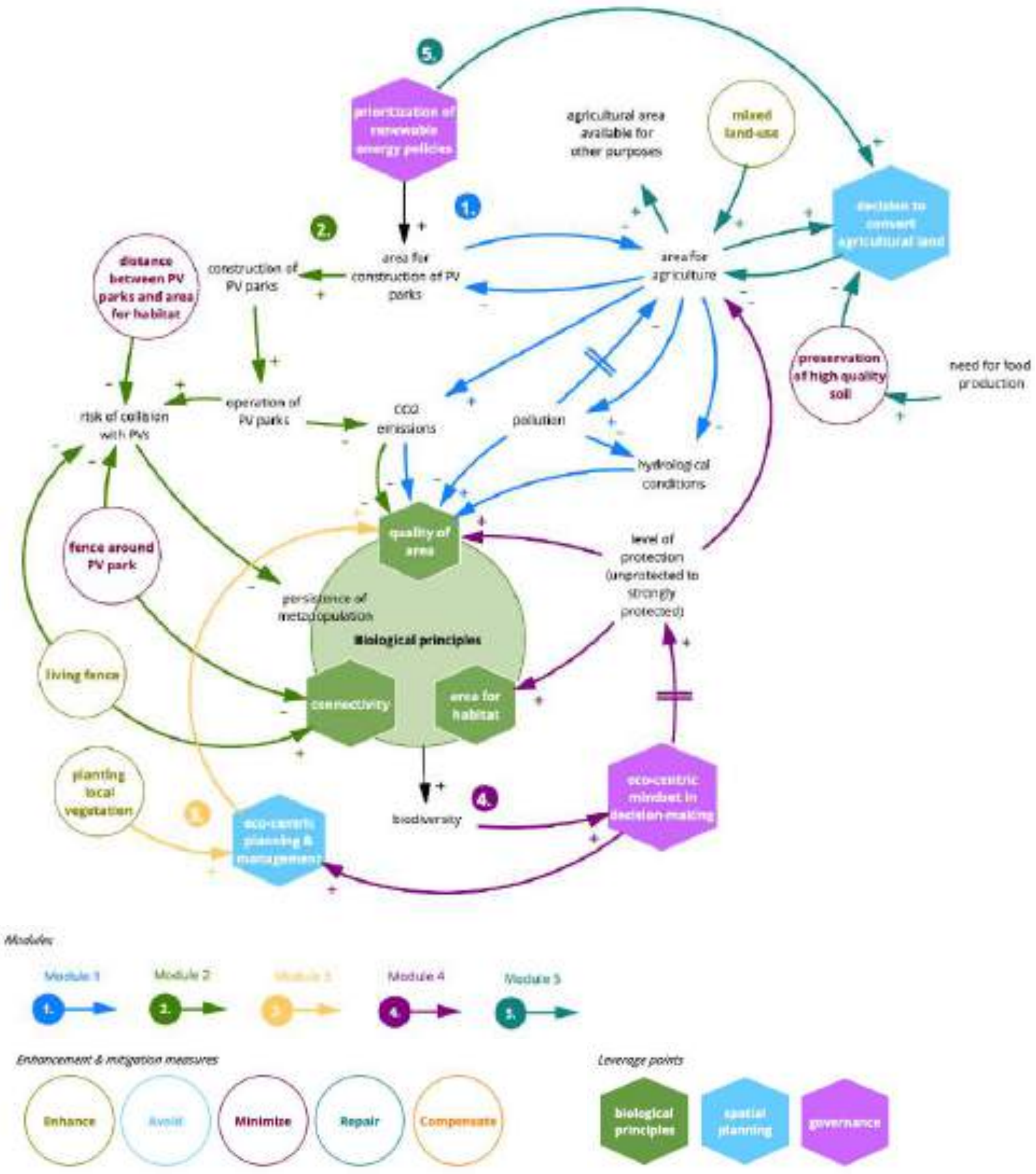

Figure 1616: CLD for converting agricultural land, illustrated by the case of establishing PV parks. (Source: Authors' model).

8.3 Environmental assessment as a support for spatial planning

SEA and EIA have the potential of clearly defining the impacts described in this system and, as such, is responsible for communicating to decision makers not only the direct impacts associated with the construction of new infrastructure, but also how to designate areas for land-use change and which land provides the greatest potential for conversion. For this case, it becomes a matter of advocating for the conversion of agricultural land, especially with low-quality soil, to allow for other land-uses that directly benefit the Biological Principles and provide better conditions for leveraging biodiversity. The **decision to convert agricultural land** is therefore highlighted as a leverage point for spatial planning, which is a planning decision that the SEA and EIA can help support.

This case mapped the **prioritization of renewable energy policies**, which is identified as a leverage point for governance levels that can push policies that promote a green transition or other sustainability agendas. As such, the new land use designated to the former agricultural areas does not need to be the construction of PV parks but can be any land use that aligns with the policies being promoted on governance levels. The impacts described through SEA and EIA have the potential to inform decisions on which policies have the greatest transformative potential and, thus, should be at the forefront of strategic planning to provide the best conditions for accommodating societal goals and biodiversity objectives.

Furthermore, enhancing leverage points embedded in the Biological Principles does not only grant intrinsic value of improving biodiversity, but it also has an effect on the philosophical and psychological underpinnings that guide decision-making. Therefore, promoting an **eco-centric mindset in decision-making** is identified as a governance leverage point. Having an eco-centric mindset is not only informed by the SEA and EIA, but also by the overall success of enhancing biodiversity, thus creating a positive learning loop. This influences the weight we grant to environmental assessment as a decision-making support as well as how we make decisions as a result. It also positively influences the **eco-centric planning and management**, identified as a crucial leverage point for spatial planners.

Lastly, SEA and EIA also have a role in the proposal of enhancement and mitigation measures that both respond to the negative impacts imposed by the construction of new infrastructure, in this case, PV parks, as well as enhance the potential positive effects and further accelerating the enhancement of biodiversity. The enhancement and mitigation measures identified in this case apply mostly to the impacts arising from the operation of the PV parks themselves. In other words, they address the impacts occurring once the decision to convert agricultural land has been made and the land-use has been designated to the promotion of renewable energies.

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9 Habitat conversion

> The mitigation hierarchy is challenged – One issue is the relative widespread and increasing use of compensation, which should be the last resort according to the hierarchy.
>
> Larsen et al., 2018: 292

The conversion or land take of nature areas is depended on the type of nature and the level of protection. The distinction between strongly protected areas, such as Natura 2000 sites, and less protected or unprotected areas play a role in understanding the possibilities and impacts of land take.

Natura 2000, the network of protected areas across Europe, are designated under the EU birds and habitat directives. Development in or near Natura 2000 sites is subject to strict regulation and assessments to avoid significant negative effects on the integrity of the site, which significantly delimit the extent of land take within these areas. Only in the case, where no feasible alternatives can be demonstrated and a development is of overriding public interest, dispensation is possible.

At the other end of the spectrum, there are unprotected areas with no legal protection for conservation or biodiversity. These areas can include undeveloped areas, agricultural land, and forests without any special protection. The less stringent regulation in these areas makes it easier to obtain permission for a land-use change, with less scrutiny and control.

Between these extremes are less protected areas, which are regulated through national or regional laws in individual Member States. One example is the Danish Nature Protection Act including protection of e.g., lakes, heathland, streams and pastures. Despite protection, it may be possible to obtain dispensation for land-use change, possible accompanied with demands for compensating the destruction or alteration of natural values. Neglecting land take of small areas can lead to an oversight of the incremental and cumulative impacts on natural habitats (Fahrig et al., 2019) and challenge the prevention principles upon which the environmental assessment directives are built upon (Larsen et al., 2018).

Very critical and necessary attention points are that our understanding of how quickly compensated nature develops is notably limited, the documentation for long-term effects of compensation is limited, and that the replaceability of different types of nature is significant variable (Nyggard et al., 2018).

9.1 Planning case: Urban development in protected areas

Urban development is, as mentioned before, a direct driver of biodiversity loss through land take and habitat destruction driven by indirect causes such as population growth, urban sprawl, demographic changes and consumption patterns.

Types of urban development cover a wide range of developments such as infrastructure, expansive transport networks, and buildings for public or commercial use. Further, the urban development can be characterised as high-density or low-density.

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Urban development within or adjacent to protected areas represents a particularly challenging case. Protected areas are designated to conserve natural habitats and species but needs for urban development may threaten their integrity. In this case, the system and corresponding CLD relates to the planning of urban development in protected areas. Specifically, the situation in which dispensation is possible due to the less strict regulation for conservation and biodiversity. The dispensation of urban development in protected areas stems from different socio-economic and regulatory drivers. One driver can be the regulations governing land use in protected areas, which may allow exceptions or dispensations based on e.g. social and economic considerations. The pressure from urban expansion is another cause, which is especially relevant in the scenario of areas located near urban centres. Further, development priorities such as tourism or infrastructure development may justify development in protected areas.

While some urban development contributes to biodiversity loss, it can also present opportunities for biodiversity enhancement if designed with ecological principles and sustainable practices in mind. Nature-based solutions is an example of opportunities for enhancing biodiversity through urban development, e.g. by restoring habitats and utilizing ecosystem services. Green infrastructure is another opportunity, involving a network of natural and semi-natural spaces to also deliver ecosystem services. Further, urban development can also involve fostering community engagement and awareness.

To illustrate these dynamics, data from the analysed SEA and EIA reports are used to illustrate the above dynamics in the following.

9.2 CLD for the conversion of habitat for urban expansion

Converting habitat for the purposes of urban expansion has an evident influence on the leverage points from the Biological Principles, as habitat, that otherwise should be coherent and connected, is compromised for other purposes. **Fejl! Henvisningskilde ikke fundet.** depicts the impacts from policies promoting urban expansion, largely driven by an increasing population, when that expansion draws upon areas formerly designated as areas for habitat, especially when those areas are protected/strongly protected and require dispensation for development. This case consists of five primary 'modules' of impact: 1. the dispensation of urban expansion on protected areas (blue arrows), 2. the direct impacts from the permanent structures derived from urban expansion (green arrows), 3. the direct impacts from eco-centric planning and management (yellow arrows), 4. the indirect impacts stemming from governance levels and decision-making (purple arrows) and 5. indirect impacts from governance decisions concerning protection level of habitats (teal arrows).

The leverage points stemming from the Biological Principles, mitigation measures, and additional case specific leverage points identified for spatial planning and governance have been outlined in bold in the text below.

1. Policies promoting urban expansion lead to more urban expansion on a general level, but they also lead to more **dispensation** that allows for urban expansion onto natural areas, assuming that the needs for urban expansion override the integrity of the protected areas in decision-making. When natural areas are granted dispensation, there is less **area for habitat**. Mitigating these impacts requires the **compensation** and/or **rehabilitation of the area for habitat** that is lost, which effectively increases the **area for habitat** and overtime, also has a positive effect on

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the **quality of areas**. Measures should be taken to ensure that the **quality of the area** is at least equal to, if not better, than the area it replaces/repairs. Moreover, the more **area for habitat** there is, the less need for **rehabilitating** and **compensating areas** there is. One way to avoid the impacts derived from dispensation altogether is to **limit the dispensation** granted for conversion of habitats, identified here as a mitigation measures.

2. Once dispensation has been granted, urban expansion takes place in the form of **permanent structures**. These **permanent structures** range from new housing to new infrastructure development (hospitals, roads, bridges, tourist facilities, waste management facilities, etc.). These permanent structures decrease the **area for habitat**, but through enhancement measures such as **nature-based solutions** and **blue-green infrastructure**, the **quality of the area** designated for urban expansion can be improved to better accommodate species and natural environments. **Nature-based solutions** and **blue-green infrastructure** also contribute to promoting eco-system services, further enhanced by high **quality**. Furthermore, establishing permanent structures can increase the fragmentation of habitats, which links to an entirely new subsystem of impacts described in more detail in chapter 10.

3. **Eco-centric planning and management**, focused on providing the best conditions for biodiversity, can be another way of ensuring quality of the area which in turn leads to better conditions for ecosystem services, which can be seen as an output of the system.

4. The enhancement of biodiversity further concretizes biodiversity values in governance, here referred to an **eco-centric mindset in decision-making**. This **eco-centric mindset** promotes more **eco-centric planning and management** as well as the use of enhancement measures, such as the **establishment of new protected areas** (additional to those being compensated and/or rehabilitated) or a **decision to extend the protected area** altogether. Both enhancement measures increase the total **area for habitat**.

5. The next module outlines the impacts of the governance level in **strengthening legislation for greater protection** of natural areas, the implementation of which is challenged by policies promoting urban expansion. In other words, the more society calls for urban expansion in response to population growth, the less attention will be granted to more and stronger protection of natural areas. Conversely, the greater the presence of an **eco-centric mindset in decision-making** (resulting from increased biodiversity and biodiversity values), the more policies and **legislation for greater protection** will be implemented. Thus, it becomes a prioritization matter for governance levels between the need for urban expansion and the desire to uphold eco-centric values when planning. Increased levels of protection, stemming from more legislation, results in less **dispensation for urban expansion**, and thus, an increase in the overall **area for habitat** as well as the **quality of that area**, assuming that areas with a high potential for biodiversity (and thus a higher quality) are those areas that are most strongly protected.

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Causal map tool of cause-effect relations and biodiversity mitigation hierarchy connected to SP

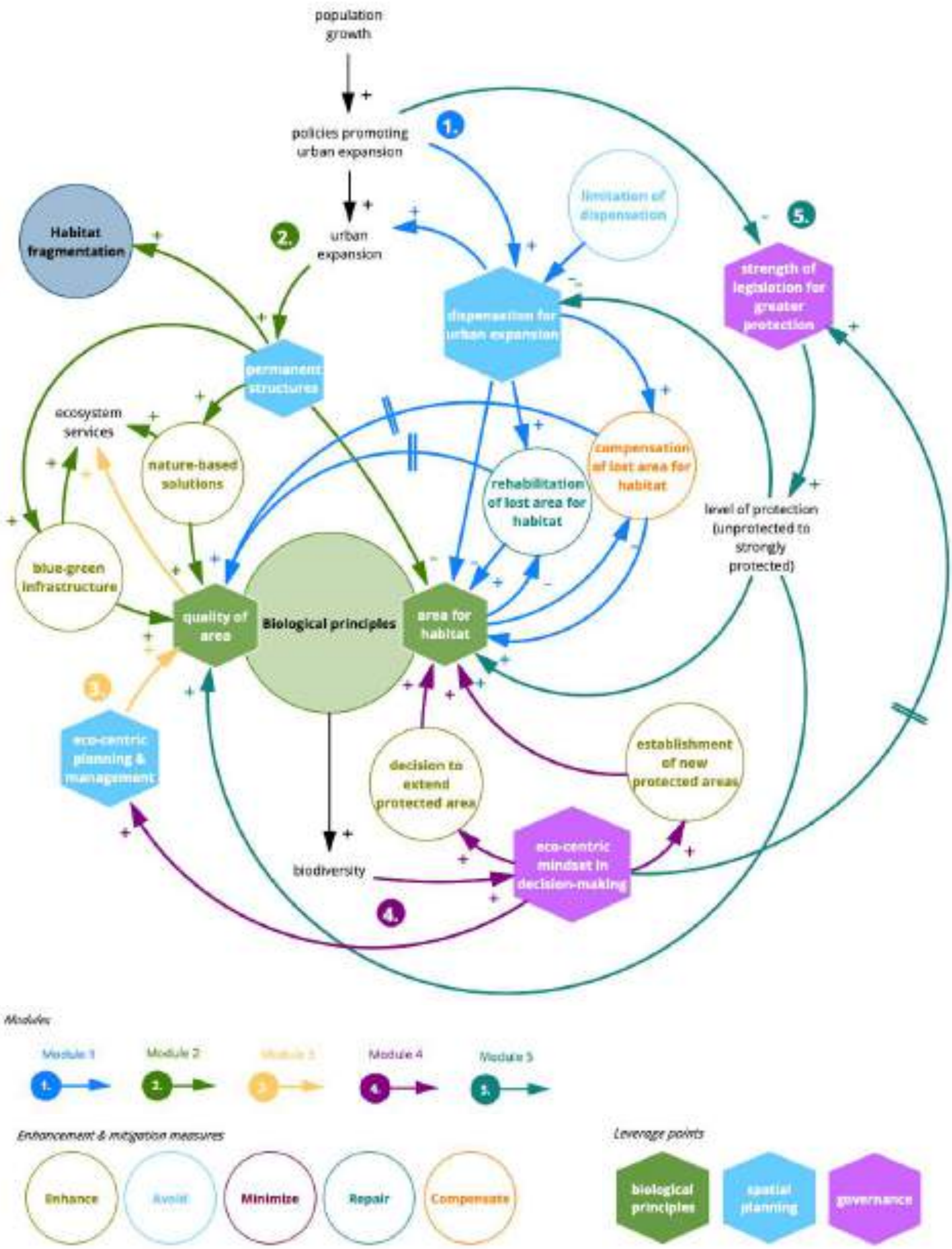

Figure 17: CLD for land-take of protected nature area, illustrated by the case of new urban development. (Source: Authors' model).

9.3 Environmental assessment as a support for spatial planning

In this case, SEA and EIA have the potential of analysing impacts from urban expansion and how dispensation of protected areas has consequences on the leverage points for biodiversity, referring primarily to the **quality of the area** and the **area for habitat**. The extent to which areas for habitat receive dispensation depends on their protection status – strongly protected areas do not elicit dispensation, while protected areas can elicit dispensation depending on the proposed plan/project. Unprotected areas do not require dispensation and can therefore be freely used for land-use change for urban purposes.

This example focuses on **dispensation for urban expansion** but could apply to any development that draws upon natural areas and accommodates population growth or any other societal drivers. EA can place focus on the decisions and on the different approaches to designing a plan/project that a planner can make. In this case, EA can help to identify opportunities for enhancing biodiversity through informing the location of urban expansion. This could be a matter of whether development should be permitted through protected areas or whether an alternative placement should be prioritized, such as avoiding **areas for habitat** altogether or drawing in unprotected nature that does not require dispensation and thereby preserving protected and strongly protected areas with high potentials for biodiversity. For this reason, **dispensation for urban expansion** is emphasized as a leverage point for spatial planners, where decisions to avoid the impacts altogether through the **limitation of dispensation** on strongly protected/protected areas or to mitigate the impacts through **rehabilitation** or **compensation of lost area** can be implemented.

The spatial planning leverage point of **dispensation for urban expansion** is interconnected with the decision to **strengthen legislation for greater protection**, identified as a governance leverage point. Here, SEA and EIA have the potential to inform of the biodiversity potentials coming from strengthened protection of natural habitats and can encourage the **eco-centric mindset** (also a governance leverage point) that ripples into policy- and decision-making. It is important for environmental assessment to also shed light on the potential enhancement measures that can be adopted by a planner wanting to plan for the enhancement of biodiversity, rather than its compromise for the sake of development. This includes the extension or establishment of new protected areas, but also signifies the importance of an eco-centric mindset when managing the urban area (making **eco-centric planning and management** a crucial leverage point for a spatial planner).

Once urban expansion has been granted a location, regardless of whether this has required the dispensation of protected areas, environmental assessment can also inform spatial planners in terms of the design of the **permanent structures** that the urban expansion entails. This could be a matter of identifying opportunities for eco-system services through **nature-based solutions** and/or **blue-green infrastructure**.

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10 Habitat fragmentation

An ecosystem is a tapestry of species and relationships. Chop away a section, isolate the section, and there arises the problem of unravelling.

Quammen, 1996

Fragmentation of habitats concerns the division of living spaces into smaller, more isolated areas. This fragmentation is a direct consequence of infrastructure development and is considered one of the primary factors in the decline of biodiversity in Europe (Damarad and Bekker, 2003; EEA, 2011; Hoyos-Rojas et al., 2023).

We define fragmentation as a landscape-scale process that includes (a) reduction in total habitat area, (b) increase in the number of habitat patches, and (c) decrease in sizes of habitat patches.

Lawrence and Beirkuhnlein, 2023

Landscape fragmentation varies across European regions and is an outcome of especially policy and socio-economic drivers of development.

The effects of fragmentation is found to be more likely in regions with "higher population density, higher gross domestic product per capita, a lower unemployment rate and higher volumes of goods and passengers transported, with a population that is well educated and environmentally aware (as a response to advanced environmental degradation), fewer natural barriers (e.g., few high mountains), and if the region is already naturally broken up into islands." (EEA, 2011: 16).

Albeit protecting large areas, Fahrig and colleagues argue for also protecting small patches, noting that the widespread focus on the impacts of fragmentation has contributed to this lack of concern for conservation of small patches (Fahrig et al., 2019). They hereby also reflect upon the cumulative impacts, and that this oversight has led to a "cumulative erosion of natural habitats, one small patch at a time, as the log of these patches foes unnoticed…" (do: 185).

For the accomplishment of the EU goal of establishing additional protected areas aiming for preserving 30% of terrestrial land by 2030, the study by Lawrence and Beierkuhnlein (2023) is very relevant. In their study of fragmentation around European Nature 2000 areas, they find that prioritization of expanding protected areas in low fragmented areas is the most effective strategy to safeguarding biodiversity (Lawrence and Beierkuhnlein, 2023).

10.1 Planning case: Linear infrastructure development

Linear infrastructure development, such as roads and railways, have significant potential consequences for nature conservation efforts, particularly in Europe, where infrastructure development is continually expanding. The geographical extent of infrastructure results in direct and indirect consequences for landscapes and ecosystems. One of the most immediately apparent and measurable impacts is the loss of land. The total land uptake includes the infrastructure itself (e.g.,

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roads or railways) and the adjacent areas such as verges, slopes, and buffer zones required for construction and maintenance.

The loss of land translates into the loss of habitats, as these areas can no longer be utilized by wildlife due to altered living conditions. As highlighted by The European Environment Agency (with reference to Road Ecology by Richard Forman et al., 2003) the habitat loss leads to reduced habitat quality, increased wildlife mortality, and decreased connectivity and that the cumulative effect over time is a high risk of extinction (EEA, 2011: 16).

If current trends in infrastructure development continue without adequate mitigation measures, the risk of extinction for many species will likely increase, undermining broader conservation goals.

The causalities and environmental impacts observed from larger infrastructure projects, can be extended to other, smaller scale infrastructure developments. While the scale and intensity of the impacts may vary depending on the size, types, and location of infrastructure, the underlying ecological principles and patterns of disturbances remain largely consistent.

Even smaller infrastructures such as local roads and trails, utility corridors or pipelines require some amount of land clearance and modification, which can lead to direct loss of habitats and fragmentation of the surrounding landscape. They may also have edge effects, due to e.g. light and pollution into adjacent areas, which can degrade habitat quality, and they can facilitate the spread of invasive species. Further, smaller infrastructures can lead to increased human access, which can result in littering or other forms of human disturbances that can harm the natural environment.

Additionally, while each small infrastructure may have seemingly limited impacts on its own, the cumulative effects of multiple small-scale developments can be substantial, especially when they are built in proximity or over time.

10.2 CLD for fragmentation due to linear infrastructure development

Linear infrastructure, whether it be e.g. roads, railways, or bike paths, are often a result of new transport policies advocating for more interconnectedness and accessibility. Accommodating these needs nevertheless impacts the leverage points for the Biological Principles, through first and foremost the inevitable fragmentation of habitats. The impacts associated with linear infrastructure as well as potential enhancement and mitigation measures are illustrated in **Fejl! Henvisningskilde ikke fundet.**. The system of impacts consists of four 'modules': 1. the direct impacts from fragmentation of habitats (blue arrows), 2. the direct impacts from the construction of linear infrastructure (green arrows), 3. the direct impacts of the implemented management initiatives once the linear infrastructure has been developed (yellow arrows) and 4. the indirect impacts of governance mindsets that influence policy (purple arrows).

The leverage points stemming from the Biological Principles, mitigation measures, and additional case specific leverage points identified for spatial planning and governance have been outlined in bold in the text below.

1. The construction of linear infrastructure inevitably leads to the fragmentation of habitats which has a direct negative impact on the **connectivity** of these habitats, and thus, directly influencing the Biological Principles. To minimize the impacts of decreasing **connectivity**, **wildlife**

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corridors and crossings can be implemented as a mitigation measure. They promote more **connectivity**, although not to the same level as before. If habitats are largely connected, there is less need for **corridors and crossings**.

2. The construction of linear infrastructure decreases the **area for habitat**, assuming that it disrupts currently designated nature areas. It also contributes to pollution of various sorts (noise, light, air, etc.), decreasing the **quality of the area**. Mitigation measures such as **noise and light barriers** decrease the impacts of pollution, thereby improving **quality of the area**, but in turn further fragments the area and decreases **connectivity**. Additionally, the construction of linear infrastructure can create conditions that favour invasive species (due to their remarkable persistence in low-quality areas) over native species, which compromises genetic diversity and sets the system of Biological Principles in motion. The prominence of invasive species can be minimized through mitigation measures, such as using **uncontaminated soil** in the construction of the linear infrastructure as well as **monitoring of invasive species** to ensure they are maintained and managed. Generally speaking, enhancing biodiversity as a result of spatial planning that improves the leverage points embedded in the Biological Principles increases the overall resilience of the system and combats invasive species.

3. **Eco-centric planning and management** can help to improve the **quality of the area** through mitigation measures, such as **seasonal construction** (i.e. avoiding construction during breeding seasons) and **phased construction** (dividing construction into different phases to minimize the cumulation of disturbances at a given time). Additionally, planning for **species-rich infrastructure verges** (referring to the area directly alongside the road/railway/path) can further enhance the **quality of the area** in addition to playing a role in **eco-centric planning and management**. **Monitoring of invasive species** is also an approach to **eco-centric planning and management**, further improving the **quality of the area**.

4. As was the case in the two prior examples, increased biodiversity promotes an **eco-centric mindset in decision-making**, further promoting more **eco-centric planning and management** initiatives. **Eco-centric mindset** leads to more eco-centric policy that may in turn result in the **consideration of alternative locations** (or designs) for linear infrastructure that avoids the natural areas as far as possible and, as such, avoids **fragmentation** in the first place. Furthermore, an **eco-centric mindset** also promotes decision-making centered around increased **public involvement and awareness**, which reciprocally enhances the prominence of an **eco-centric mindset in decision-making**.

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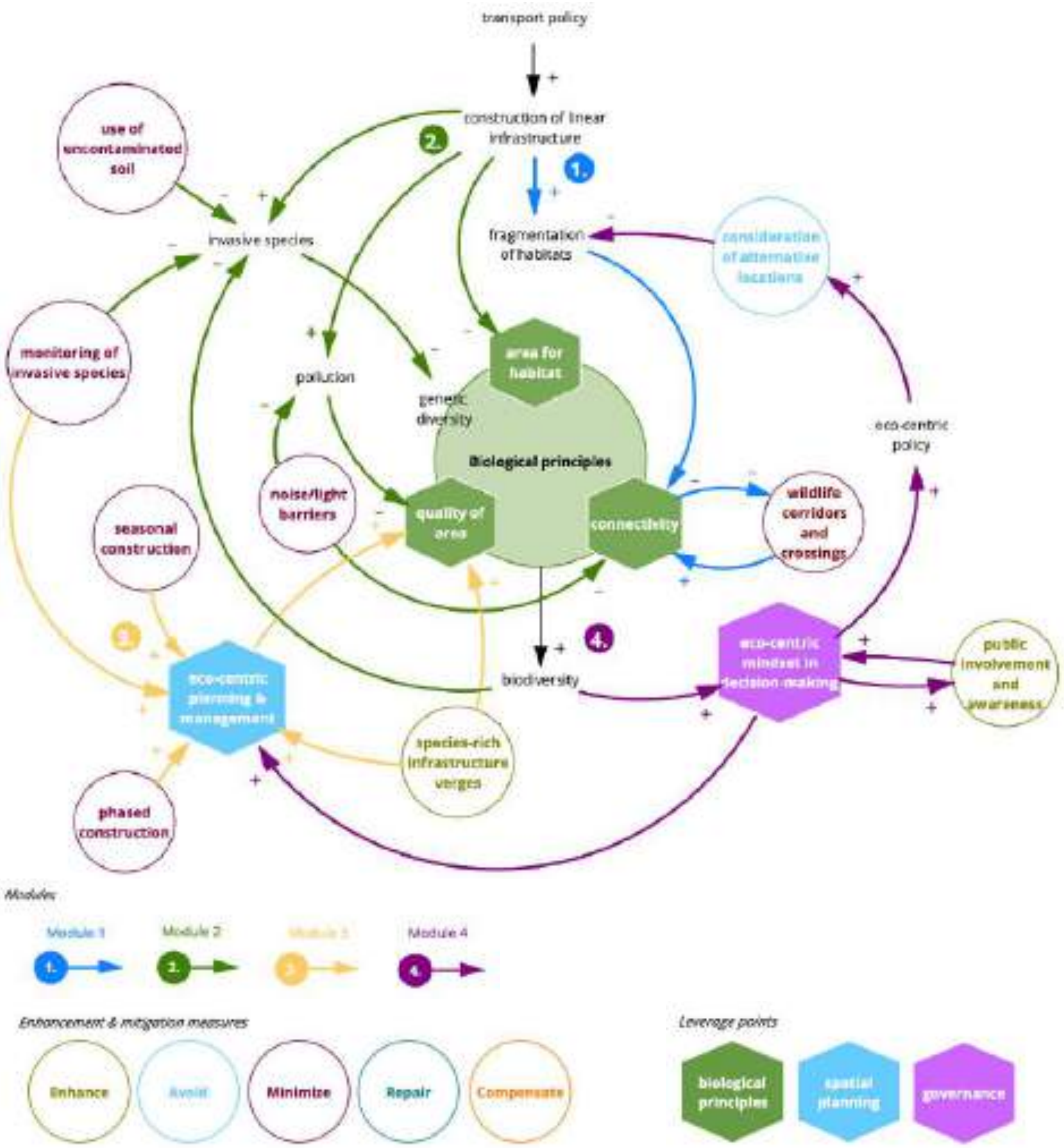


Figure 18: CLD for fragmentation of habitats due to construction of linear infrastructure. (Source: Authors' model).

10.3 Environmental assessment as a support for spatial planning

As with the other cases, the primary role of SEA and EIA is to inform of the impacts of plan/project development and to identify opportunities for spatial planners and governance levels to make decisions that enhance biodiversity. This case revolves mostly around the potential of environmental assessment in informing of and advocating against the increased fragmentation of **areas for habitat** when linear infrastructure is implemented. It again places emphasis on how a more eco-centric approach to planning and decision-making should encourage the **consideration of alternative locations** for infrastructure that do not compromise **connectivity** and **area for habitats**. Therefore, an **eco-centric mindset** is identified as a leverage point whose execution in practice should be supported by environmental assessment and the analysis of impacts and identification of enhancement opportunities. Here, the democratic position of SEA and EIA and their ability to **involve the public** through public hearings and thereby raising awareness of environmental concerns and opportunities further supports and facilitates a more **eco-centric mindset in decision-making**.

But where the impacts of linear infrastructure cannot be avoided, SEA and EIA have the potential to suggest enhancement and mitigation measures to address either the compromised **connectivity** and the weakened **quality of the area**. This includes informing of potential trade-offs, such as the **noise/light barriers** promoting the **quality of the area** but at the compromise of **connectivity**. Some of these enhancement and mitigation measures are a matter of how the linear infrastructure is managed, in which an **eco-centric planning and management** approach can be supported through the environmental assessment. Furthermore, environmental assessment as an instrument has the potential to establish a monitoring program that monitors and follows up on the impacts (in this case, the **monitoring of invasive species** is proposed).

Lastly, this impact system of fragmentation does not only apply to the development of linear infrastructure but is pertinent in any plans/projects that disrupt the coherency of natural areas. For instance, this fragmentation subsystem has also been linked to the previous case on habitat conversion for urban expansion and can apply more broadly to other cases as well. Thus, the impacts described in this system (especially those in modules 1 and 4) pertain to wide array of plans/projects.

11 New habitat development

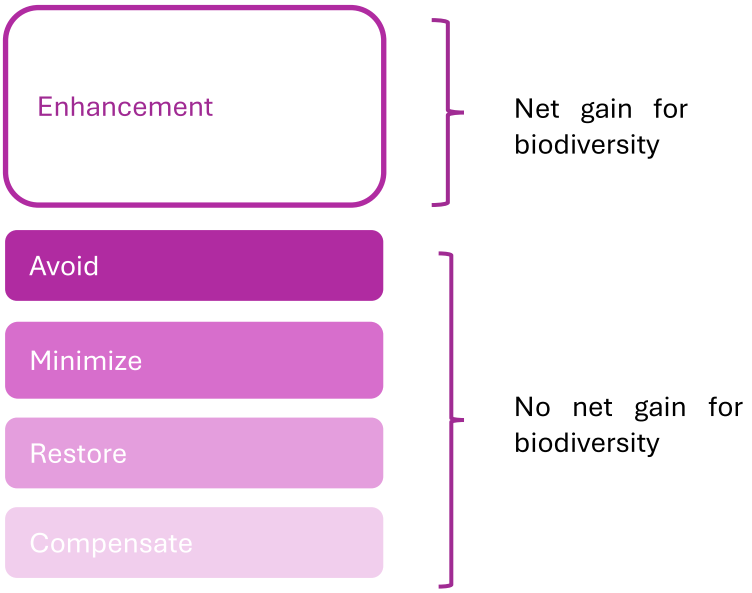
> The world should commit to the net-gain principle to give nature back more than it takes.
>
> EU, 2020: 3

Habitat creation concerns restoration, development and management of habitats. In this chapter, the focus is on habitat development involving establishing new habitats to support biodiversity and is to be seen as a strong enhancement measure for spatial planning, environmental assessment and financial- and economic instruments to support.

The habitat development can for example be in the form of green infrastructure such as green-roofs and urban parks, corridors connecting fragmented habitats, agroecology, and wetland construction which also seek to address the need for flood control and carbon sequestration.

The EU Biodiversity Strategy for protecting 30% of terrestrial land by 2030, with 10% under strict protection, provide an important framework for habitat development initiatives (EU, 2020). The deliberate establishment of new habitat is strongly related to the previous Biological Principles, 'area-species relationship' and 'source-sink dynamics' (see Section I). These principles emphasize the importance of habitat size and connectivity in supporting and enhancing habitats and biodiversity.

In the context of the mitigation hierarchy (see Figure 19), the creation of new habitat must seek to contribute to a net gain in biodiversity, by not only mitigating potential losses and threats but also actively enhancing biodiversity.



Enhancement refers to genuine improvement of the natural heritage interest of a site or area through better management, or the addition of new or better habitats or features than currently present

Rajvanshi et al., 2011: 182

Figure 19: The hierarchy of enhancement and mitigation.

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11.1 Planning case: Afforestation

Afforestation is defined in the EU Taxonomy as "Establishment of forest through planting, deliberate seeding or natural regeneration on land that, until then, was under a different land use or not used. Afforestation implies a transformation of land use from non-forest to forest.". So as for any other type of land-use change, afforestation has both direct and potentially also indirect impacts on biodiversity.

Afforestation functions as an important strategy for creating new habitats and enhancing biodiversity.

The afforestation can contribute to biological diversity by creating habitats for a range of species, genetic diversity and ecosystem services. Elements of the ecosystem services are mitigation of climate change, recreational and health aspects, surface- and groundwater protection, and decrease erosion risk.

Forest biological diversity is a broad term that refers to all life forms found within forested areas and the ecological roles they perform. As such, forest biological diversity encompasses not just trees, but the multitude of plants, animals and microorganisms that inhabit forest areas and their associated genetic diversity.

Forest biological diversity can be considered at different levels, including ecosystem, landscape, species, population and genetic. Complex interactions can occur within and between these levels. In biologically diverse forests, this complexity allows organisms to adapt to continually changing environmental conditions and to maintain ecosystem functions.

FAO and UNEP, 2020: 3

Afforestation can potentially also lead to negative impacts and potential trade-offs. Key factors to secure positive impacts for biodiversity include:

- Size of un-fragmented natural area. A recommendation is that a natural area should be at last 1.000 hectares and preferable over 5.000 hectares (Biodiversity Council, 2022).

- Conversion of already cultivated forest and agriculture – and establishing forests near existing natural areas (Petersen et al., 2024).

- Type of forest. Both deciduous and coniferous forest support forest-dwelling species such as animals, plants, and fungi. While most forest-dwelling species are found in deciduous forests, coniferous forests host specialized species predominantly associated with them (Petersen et al., 2016).

- Species introduction. Introducing native species in afforestation projects supports biodiversity, whereas non-native species can negatively impact native species through spread and competition, affecting ecosystem functions and processes. For each region, non-native species must be identified.

- Public and private payment schemes to incentivize forest ecosystem services (EU, 2021).

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11.2 CLD for new habitat development through afforestation

Developing new habitat is typically driven by policies for biodiversity (wanting more habitat to accommodate more species) and/or policies for climate mitigation (wanting nature areas that accommodate needs in terms of climate change). This case looks upon the impacts of afforestation, or the planting of new forests, on the Biological Principles and what spatial planning and EA can do to enhance biodiversity. The system is divided into five 'modules': 1. the direct impacts of planting a diverse forest in terms of biodiversity and meeting timber demands (blue arrows), 2. the direct impacts from afforestation (green arrows), 3. the direct impacts from designing and managing the forest (yellow arrows), 4. the indirect impacts from governance levels (purple arrows), and 5. the direct impacts associated with carbon sequestration (teal arrows).

The leverage points stemming from the Biological Principles, mitigation measures, and additional case specific leverage points identified for spatial planning and governance have been outlined in bold in the text below.

1. The policies for biodiversity encourage high forest diversity, while a demand for timber encourages timber production that policies for biodiversity then consequently counteract, as production forests tend to be less diverse and more monocultural than forests for promoting biodiversity. In that sense, timber production results in less forest diversity, worse hydrological conditions, and more nutrient pollution (through pesticides and fertilizers), which worsens hydrological conditions even further. Compromised hydrology leads to the worsening of the **quality of the areas**. On the other hand, the greater the diversity of the forest, the greater the **quality of the area**, meaning that a diverse forest contributes more positively to the Biological Principles than production forest for timber production.

2. The policies for biodiversity as well as the demand for timber are also the primary drivers of **afforestation** which brings with its own impacts. First and foremost, **afforestation** increases the total **area for habitat**, as new forest, regardless of the type of forest that is planted, will lead to more habitat for different species. Similarly**, afforestation** also improves the **quality of the area**, which results in the promotion of ecosystem services. Through the enhancement of both **area for habitat** and **quality of the area**, **connectivity** is also improved (as the mechanisms within the Biological Principles suggest). **Connectivity** can be further enhanced by planning for the **proximity of afforestation to other natural habitats**. Yet, increased **connectivity** also provides better conditions for the spread of **invasive species** which reduces genetic diversity and negatively impacts the biological leverage points. This can nevertheless be combatted by promoting activities that enhance the leverage points, effectively promoting biodiversity, and thereby, decreasing the impact of invasive species.

3. **Eco-centric forest planning and management** encourages more forest diversity (improving **quality of the area**) as well as generally enhancing the quality of the area. An output of better-quality results in ecosystem services. Examples of enhancement measures that constitute **eco-centric forest planning and management** include paying particular attention to planting a diverse selection of species (**forest species composition**), **native forest species**, and **climate-change adaptive species**. **Eco-centric forest planning and management** also leads to **choosing climate change resilient locations** for **afforestation**, which in turn, leads to more **eco-centric planning and management**.

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4. In a governance perspective, the promotion of biodiversity leads to a more **eco-centric mindset in decision-making**, which promotes more policies for biodiversity. It also encourages **reducing the use of pesticides and fertilizers**, which in turn reduces nutrient pollution, improving hydrology and the **quality of the area**. Having an e**co-centric mindset in decision-making** also encourages **eco-centric forest planning and management**, also improving the **quality of the area**.

5. Policies for climate mitigation leads to the need for carbon sequestration. One way to address this need is through planning for **afforestation**, which in turn leads to the sequestering of carbon, reducing the amount of CO_2 emissions and reducing the need for more carbon sequestration. At the same time, the reduction of CO_2 emissions improves the **quality of areas**, which improves the area's ability to sequester carbon. On the other hand, timber production produces more CO_2 emissions and as such, reduces the **quality of the area** and limits its future potential for carbon sequestration.

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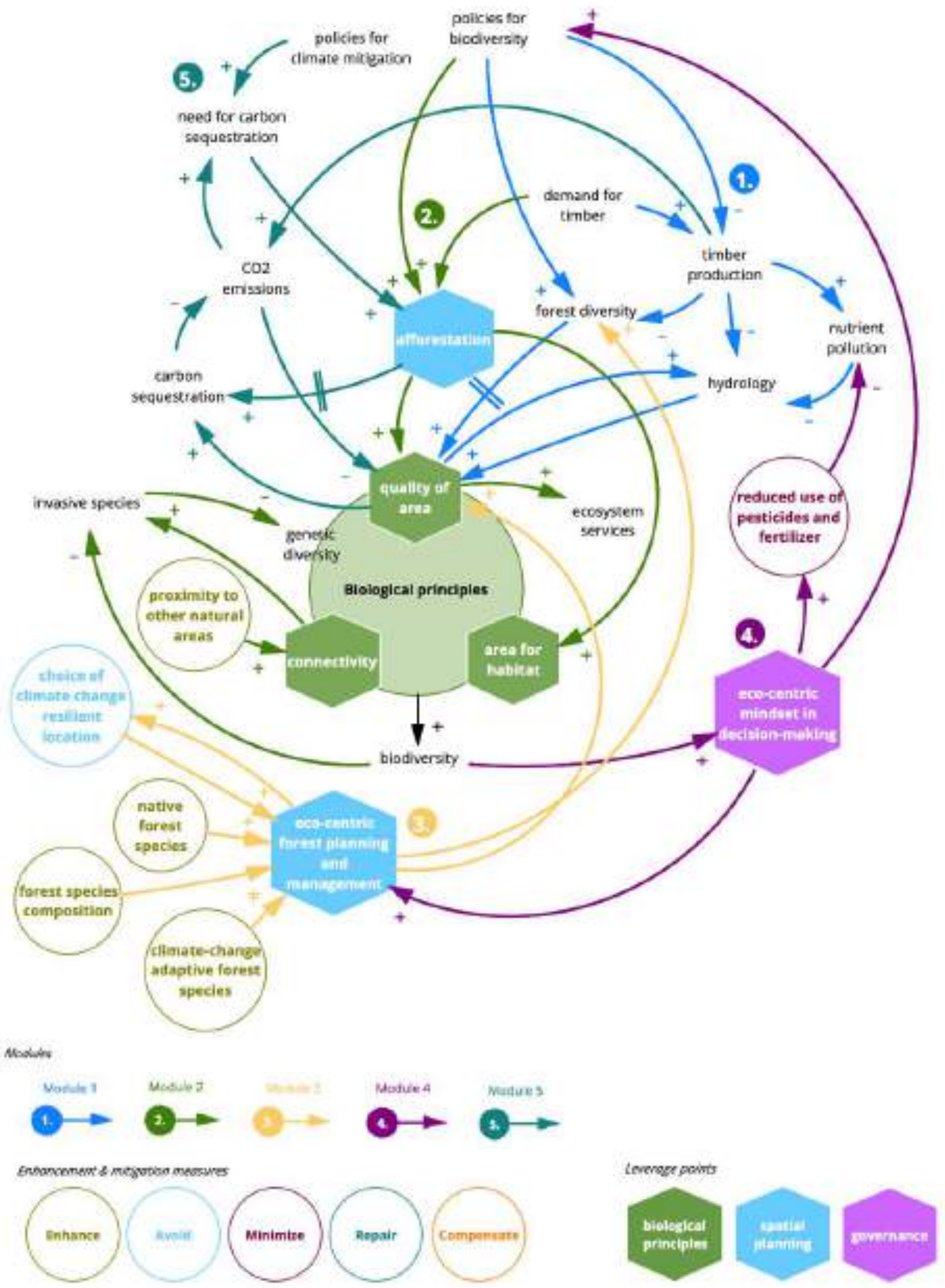

Figure 20: CLD for new habitat development through afforestation. (Source: Authors' model)

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11.3 Environmental assessment as a support for spatial planning

SEA and EIA are, in this case, instruments for promoting **afforestation** that maximizes potentials for biodiversity. This is first and foremost done through the promotion of diverse forests as opposed to forests for timber production, which places emphasis on **afforestation** as a response to policies for biodiversity rather than the demand for timber. The prioritization of policies relates back to module 5 presented in the initial case on the conversion of agricultural land, where similar principles regarding the prioritization of certain policies over others determines the designation of land-use, and in this case, determines which type of forest is planted.

The prioritization of policies is not only a matter of planting forests for biodiversity or for timber production, but also a matter of policies for climate mitigation. As depicted in the CLD, **afforestation** is one way of sequestering carbon, but if policies for climate mitigation are the primary drivers for designating land uses, other forms of land use could also be promoted, such as rewetting peatland or more regenerative agriculture. Environmental assessment can thereby be an instrument for supporting spatial planning and the designation of land uses, and module 5 from this **afforestation** case becomes applicable to a wide range of plans/projects aimed at sequestering carbon. **Afforestation** is also marked as a spatial planning leverage point for its important contribution to both biodiversity and climate change policies.

Not only does the competition between dominant policies become relevant for determining which land use receives priority when area is a restricted resource, it also plays a factor in what kind of land use is compromised for, i.e. a new forest, if the decision for **afforestation** has been made. This aspect of spatial planning is outside of the scope of the CLD model but could suggest that forests should not replace wetlands as they also contribute to not only climate mitigation, but also biodiversity. Thus, SEA and EIA become pertinent in selecting the right location for **afforestation** for maximizing biodiversity.

Environmental assessment also has a role in promoting **eco-centric forest planning and management** that acts as a primary driver for forest diversity. This **eco-centric forest planning and management** has as such been identified as a leverage point for spatial planners. Informing of the enhancement and mitigation measures a spatial planner can adopt to promote **eco-centric forest planning and management** should therefore be another focal point for environmental assessment. The **eco-centric forest planning and management** is reinforced by the **eco-centric mindset in decision-making**, also making this a catalyst for enhancing biodiversity in planning, albeit on the governance level. Potential enhancement and mitigation measures apply also to improving **connectivity** and to reducing nutrient pollution.

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12 Linking systems thinking and CLDs to BioValue arenas

BioValue has three case studies in different regions – Mafra Municipality in Portugal, Fersina River in Italy, and Mecklenburg-Vorpommern in Germany – to address spatial planning challenges and enhance biodiversity. These case studies serve as arenas for transformative action to implement and experiment with the BioValue research frameworks. The goal is to safeguard and enhance biodiversity through spatial planning practices and infrastructure development.

First, the chapter provides a presentation of each arena, including an overview of the context, background, and strategic focus. This sets the stage for understanding how these arenas relate to systems thinking as presented through the CLDs.

Then follows an exploration of how these arenas relate to the modules presented through the CLDs that incorporate conversion of agricultural land, habitat conversion, habitat fragmentation, new habitat development, and the Biological Principles

The recommendations presented here are derived from applied systems thinking and analysis of the CLDs, identified leverage points and suggested mitigation and enhancement measures.

It is important to note that these preliminary recommendations are merely exemplary and will serve as a foundation for more detailed application in each specific arena. The further refinement and application of these recommendations will be conducted in close collaboration with the other partners in the BioValue project and the specific arenas in WP4. This collaborative approach ensures that the recommendations are not only theoretically sound but also practically applicable, considering the local nuances, stakeholder inputs, and specific challenges and opportunities faced in each arena.

By unfolding these recommendations, the project aims to provide actionable insights that can guide spatial planning and policy development in each arena. The integration of SEA and EIA into these processes is key to ensuring that environmental, economic, and social goals are balanced effectively, fostering sustainable development that enhances biodiversity outcomes.

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12.1 Municipal Spatial Planning: The arena of Mafra Municipality

Context and background
Mafra Municipality, located in the Lisbon metropolitan area, is experiencing significant tourist influx and urban expansion, stressing its natural resources and biodiversity (Monteiro and Soares, 2024):

- While increased tourism has brought economic benefits it also poses threats to biodiversity and local natural values, which are integral to the region's identity.
- The need to control urban expansion while preserving green and blue spaces is critical, particularly in light of the attractiveness of the region to both residents and tourists.
- Another core component in the Mafra arena is ensuring that spatial planning aligns with contemporary environmental legislation and incorporates biodiversity as a core component.

Strategic focus areas for Mafra
Based upon transformation workshop in the BioValue project, crucial insights and strategic directions for addressing these challenges have been provided. Based upon the findings from the workshops, and explored future scenarios, the focus areas for Mafra in their planning are (Monteiro and Soares, 2024):

- Adopting an ecosystem service approach, and hereby mapping, analyzing, assessing and monitoring services.
- Emphasizing the preservation of green areas and restauration of habitats.
- Integrating ESS into the legally based planning instruments, leveraging the municipal master plan as a tool for embedding biodiversity considerations into the planning system.
- Addressing issues of socio-economic inequality, focusing on mechanisms like the transfer of development rights to limit urban sprawl and compensate market inequalities.
- Raising awareness among policymakers, decision-makers and local actors about the importance of biodiversity. This involves stakeholder engagement.

12.2 Regenerating an urban river: The arena of Fersina River

Context and background

The Fersina River arena, located within the municipality of Trento in Italy, presents different both opportunities and challenges concerning biodiversity. The background concerns the need to integrate biodiversity considerations into urban planning beyond merely recognizing protected areas. Upstream, the river flows through a rich natural area known as the 'Canyon', which is of significant environmental, historical and cultural value (Autonomous Province and Municipality of Trento, 2024).

However, as the river enters the urban area, it becomes constrained by high stone embarkments. Furthermore, the river also passes through areas slated for future urban transformation, including the construction of a new hospital. Stakeholder engagement has identified challenges (Autonomous Province and Municipality of Trento, 2024; Monteiro and Soares, 2024):

- Underutilization of the Fersina as a green and blue infrastructure
- Limited access to the river.
- The need for renaturalization efforts.
- Integration of the river into the broader urban areas of Trento.
- The need to enhance the environmental and recreational aspects of the river, especially in the Canyon area which suffers from pollution and misuse.

Strategic focus areas for Fersina River

Based upon both transformation workshop in the BioValue project and stakeholder engagement, the strategic focus areas the Fersina River arena are (Autonomous Province and Municipality of Trento, 2024; Monteiro and Soares, 2024):

- Revitalizing the Fersina River to enhance its biodiversity, especially in urban and peripheral areas. Hereunder redesigning the riverbed and its management to foster biodiversity while ensuring that the river can coexist with urban uses,
- Establishing the Canyon area as a naturalistic park, by protecting and integrating into Trento's green infrastructure and at the same time providing space for recreation and education. The potential of integrating ESS into urban environments is explored.
- Piloting ESS in urban areas, and demonstration of how urban planning can incorporate e.g. green spaces.
- Conducting economic assessments of benefits from the creation of the Canyon Park and urban fluvial parks.
- Involving local stakeholders and the public, and foster collaboration
- Improving access to the river, enhancing the vegetation management to support biodiversity, and integrating the river into the urban landscape.

12.3 Rewetting peatland and afforestation: The arena of Mecklenburg-Vorpommern

Context and background

The Mecklenburg-Vorpommern arena in Germany has been focusing on reforestation and rewetting peatlands as a climate change mitigation strategy. Rewetting peatlands is a process that involves restoring drained peatlands to their natural state. This conversion is increasingly recognized as crucial for both climate change mitigation and biodiversity enhancement. When peatlands are drained for agricultural use, they release stored carbon dioxide into the atmosphere. Rewetting these areas reduces these emissions and restores an ecosystem.

The rewetting of peatlands is though not only a planning strategy for carbon sequestration and biodiversity enhancement but also intersects with broader land-use policies and the complex drivers of biodiversity loss identified by IPBES (see Figure 1). This is to be seen in the context of Mecklenburg-Vorpommern is a region where agriculture plays a significant role, which can lead to conflicts between land use for farming and the need for biodiversity conservation.

The arena faces challenges such as small-scale land ownership, which complicated large-scale environmental interventions, and the need for better integration of biodiversity considerations into spatial planning. Key challenges in Mecklenburg-Vorpommern include (Monteiro and Soares, 2024):

- The need for adapting within institutional spatial planning system to better integrate climate change and biodiversity considerations.
- Overcoming the fragmentation caused by small-scale land ownership – presenting obstacles to large-scale rewetting projects.
- Addressing the conflicts between agricultural land use and biodiversity considerations, hereunder findings incentives for sustainable practices among landowners.
- Promoting public awareness and education concerning the importance of rewetting in climate mitigation.

Strategic focus areas for Mecklenburg-Vorpommern

Different focus areas have been identified through the transformation workshops in the BioValue project, and includes (Monteiro and Soares, 2024):

- Rewetting peatlands, hereunder identifying areas where rewetting can be most beneficial and possible to implement at a large-scale.
- Incorporation of biodiversity in regional spatial planning, which involves adapting institutional structures and planning systems.
- Addressing and resolving conflicts between agriculture and conservation by incentivizing sustainable agriculture practices.
- Raising public and institutional awareness of the importance of rewetting.
- Exploring economic and financial instruments to support landowners willing to engage in rewetting projects.

Situating rewetting peatland into a broader system perspective and the need for agricultural land conversion

While converting agricultural land back to natural peatlands is a direct driver, the decision to rewet is influenced by indirect drivers such as economic incentives, land ownership, and governance structures.

As the global demand – and competition – for land intensifies, the availability of land for peatland rewetting becomes increasingly constrained. This competition represents an indirect driver that complicates efforts to prioritize biodiversity-enhancing land uses like peatland restoration (as discussed in section 8.1).

The competition for agricultural land among different purposes, such as afforestation, food production, renewable energy (e.g. PV parcs) and urban development – directly impact feasibility and prioritization of peatland rewetting. Each of these land uses has its own set of economic and environmental justifications. The IPBES framework suggests that without careful spatial planning and governance, the expansion of different land use activities could inadvertently become a driver of biodiversity loss if it limits the availability of land for biodiversity enhancing projects like peatland rewetting.

The competing demands for agricultural land, and conversion of agricultural land, whether for renewable energy food production or renaturalization through rewetting peatland, highlights the need for integrated governance.

12.4 Examples of preliminary recommendations to the BioValue arenas

This section provides examples of preliminary recommendations for the BioValue arenas, illustrating how different modules and insights derived from the CLDs can inform the three arenas. Figure 21 demonstrates how the modules from the cases, along with the Biological Principles, can relate to the arenas.

This section first describes some general recommendations that apply to all of the arenas and provide general perspectives on the aspects of systems thinking that is fundamental for the arenas to bring with them in their further work. Second, the section provides some preliminary examples for how the modules from the CLDs can be tailored to the specific arena. The individualized recommendations provided for each arena are few, because the details of how and to what extent the modules relate to the arenas will be explored later in WP4.

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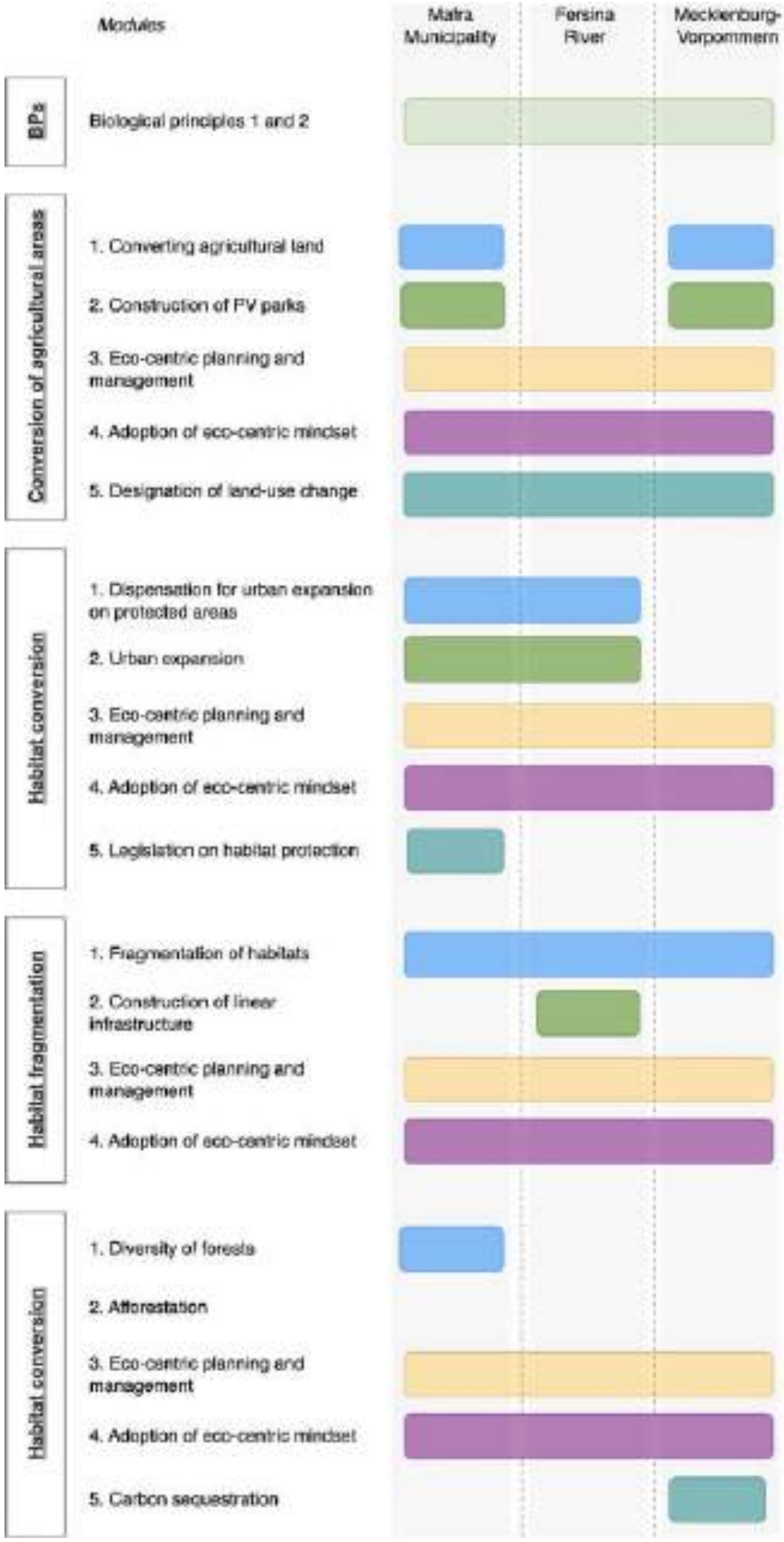

Figure 21: The relationships between the modules from the cases and the arenas from BioValue. The colors correspond to the colors of the arrows in the modules in the respective CLDs in Section II. (Source: Authors´ model).

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General recommendations – thinking in systems as a starting point

Each of the analyzed cases has presented itself to have certain generic structures and mechanisms: i. The Biological Principles apply to all cases (Figure 21, BPs in green). ii. The specific case then introduces certain variables that give rise to new system structure and behavior and enhance the level of complexity (see Figure 21, all modules). iii. The concept that the state of the ecological system resulting in biodiversity creates an eco-centric mindset (see Figure 21, modules 3 in yellow and module 4 in purple).

Leverage points connected to these generic mechanisms have different strengths (see chapter 6.2 Opportunities by utilizing leverage points), with the power to transcend paradigms and the mindset out of which the system – its goals, structure, rules, delays, parameters – arises, followed by the power to add, change, evolve, or self-organize system structure (Meadows 1997), which demonstrates the importance of EA in planning for biodiversity and driving transition.

These insights allow for three general recommendations for the arenas:

1. *Acknowledge the dynamic interactions within the Biological Principles*
   Any form of land-use affects at least one of the leverage points embedded in the Biological Principles, leading to cascading events due to the interactions within and between the Biological Principles. This will result in an impact on the state of biodiversity, which is the result of the Biological Principles.
   Before exploring the specific case, the baseline should be analyzed using the Biological Principle CLD to fully capture the state of the system before change is applied.

2. *Be aware that connecting the individual cases to the Biological Principles increases system complexity*
   Adding new, case specific elements to the system of Biological Principles, such as mitigation measures, increases the overall dynamics of the system due to various new feedback loops. These loops are most likely balancing loops that lead to different scenarios depending on the initial state of the affected system, i.e. the Biological Principles. If the system is in balance, further balancing feedback loops have the potential to enhance the system's stability. In the more likely case that the system is under pressure, not least due to the influence of the proposed project or plan, different scenarios are possible: In the best case, the balance of the overall system is restored. Due to the considerable increase of complexity, additional delays and resulting new dynamics, there is a high risk for strong oscillations or overcorrections with unintended consequences. Therefore, the choice and implementation of the proposed enhancement and mitigation measures needs to be made with great care and a profound understanding of dynamic interactions.

   Given the increased level of complexity, SEA and EIA play an especially important role in evaluating the state of the system of the Biological Principles. When adding possible solutions, expertise and knowledge about possible interactions is needed to assess how these measures possibly interact with each other and with the dynamics of the Biological Principles. Careful evaluation of different scenarios, involving experts, stakeholders and decision makers, are crucial to prevent or minimize undesirable outcomes in advance and achieve desirable outcomes, featuring the opportunities for creating a functioning system for the enhancement of biodiversity.

3. *Embrace the opportunity for closing the learning loop to gain an eco-centric mindset*
   This is the most powerful leverage point. Instead of allowing the needs of the project and plan steering the decision-making and merely applying mitigation measures to counteract potential

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negative impacts, gaining an eco-centric mindset sets the stage for improvement in favour of decision making and transformative change for biodiversity.

The leaning loop involves the understanding of the dynamics intrinsic to the Biological Principles determining biodiversity outcomes. If biodiversity is below the desired state, the connected factors within the Biological Principles need to be addressed to plan for reaching the desired goals for biodiversity. If the goals are met, the connected factors within the Biological Principles need to be stabilized and strengthened to enhance resilience. Allowing the state of biodiversity to transcend the paradigm and mindset brings a different dimension to policy and decision making as well as to the choice of more effective leverage points for mitigation and enhancement. Those causal effects ripple through the system via the Biological Principles back to the state of biodiversity, thus closing the learning loop.

Examples for applying the causal-map tool in the individual arenas

The following examples highlight only a few of the relationships illustrated in Figure 21, which shows the potential links between CLDs and the arenas and should be seen as a starting point; they reflect some of the complexities and interdependencies we see in the systems represented by the CLDs.

Continuous work and collaboration will be essential to further explore these links and derive more nuanced insights for each arena. This ongoing process will involve close engagement among project partners to ensure that the knowledge generated is effectively integrated and utilized. Following the finalization of this report, a collaborative and iterative phase will begin among project partners and with each arena. The goal will be to continually refine our understanding of the systems involved and to enhance the applicability of the recommendations.

By applying the insights collectively, we aim to enhance the transformative potential of SEA and EIA in spatial planning, contributing to more sustainable and effective planning processes in each arena context.

For instance, in the case of **Mafra Municipality** a key challenge is finding a balance between urban expansion and the preservation of green and blue spaces. This deems the case on 'Habitat conversion' particularly relevant, as it addresses the impacts on biodiversity from expanding for urban purposes at the consequence of natural areas and signifies the importance of protection status of that nature and the policies and mindsets that determine it. For this reason, all modules from 'Habitat conversion' can be used in the Mafra Municipality case. The direct impacts on both area for habitat and the quality of that area from the module on 'Urban expansion' related to the permanent structures that are built means that particular attention should be granted to ensuring that the permanent structures accommodate opportunities for biodiversity through i.e. nature-based solutions and blue-green infrastructure. The precise details of what these initiatives should be, and the biodiversity benefits they provide will be unfolded alongside the arena in the upcoming work.

The case of the **Fersina River** in Trento, Italy can use modules from all cases. The modules 'Fragmentation of habitats' and 'Construction of linear infrastructure', although originally derived from construction of a road, can be tailored to the Fersina arena to refer to fragmentation that occurs when new paths, such as bike paths, disrupt the coherent nature habitats along the river. Being strategic about the placements of these bike paths as well as the planning and management of the construction can be a fundamental consideration for the Fersina arena. Furthermore, the arena is related to the CLD on 'Habitat conversion' and the module 'Urban expansion' through the arena's strategic focus on the

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coexistence of urban and natural areas as well as the construction of a new hospital by the delta of the river. As with the Mafra Municipality arena, this directs attention to the way in which this infrastructure is planned and managed, and whether the hospital can be built in such a way that promotes nature-based solutions.

For **Mecklenburg-Vorpommern,** the modules 'Converting from agricultural land' and 'Construction of PV parks' are recommended to be considered. Combining PV parks with peatland rewetting offers a dual strategy for climate mitigation and biodiversity enhancement. The region has focused on rewetting drained peatlands to restore ecosystems and reduce carbon dioxide emissions. Exploring the opportunities for integrating PV parks within these rewetted areas can maximize land use efficiency be generating renewable energy while preserving biodiversity. PV installations can be designed to coexist with rewetted peatlands, avoiding conflicts between land-use for agriculture and conservation. The ecosystem approach for rewetted peatland is a governance strategy that can enhance the effectiveness and acceptance of systemic change in agricultural practices (Sommer and Frank, 2024). The idea of maximizing land use shows how different land uses can balance competing needs – such as energy production, carbon sequestration and biodiversity conservation – without significantly diminishing agricultural productivity. The approach is being explored in other places. One example of ongoing initiatives of combining PV installations and peatland rewetting is the German case 'Moor-PV' (University of Greifswald, 2024). Further, in the Danish context the independent environmental organization 'Green Transition Denmark' recommended a new policy for allowing not only PV installations but also wind turbines to stand on low-lying land. (Green transition Denmark, 2024).

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Section III: Applying systems thinking and analysis

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13 Methodology – applying systems thinking and analysis

Systems thinking serves as a method both for examining various complex contexts related to a problem and for comprehending complex systems (Forrester, 1994; Forrester, 1985; Richmond, 1994; Sterman, 2000; Stave and Hopper, 2007; Kopainsky et al., 2015; Arnold and Wade, 2015). Arnold and Wade (2015, p. 675) defined systems thinking as:

"a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects."

Systems analysis, which has roots in economic theory (Forrester, 1985), evolved into a methodology, as developed by Meadows et al. (2006) and the Club of Rome, that is also applicable in environmental science for understanding dynamic complexity, non-linear behaviors, and temporal changes.

This method involves a sequence of steps to identify the variables constituting a system and their interconnections through causal relationships. These relationships define the system's structure, shaping its behavior over time, which is reflected in various effects and consequences (Ehrlich, 2022; Sterman, 2000). To manage complexity efficiently, simplified versions of the system are constructed as qualitative models and causal-loop diagrams (e.g. Bureš, 2017). Systems thinking and analysis also facilitate the identification of protective measures to effectively prevent or mitigate undesirable or unforeseen outcomes due to changes (Ehrlich, 2022; Sterman, 2000).

The processes and methodologies involved in environmental assessment share numerous similarities, such as a flow-oriented approach with explicit procedural requirements and the evaluation of environmental aspects (Grace & Pope, 2021). Walker et al. (2024) confirms the applicability of systems analysis as a method in the SEA and EIA context, as it matches the needs, especially during the phases of scoping, impact prediction and evaluation, evaluation of alternatives as well as follow-up and monitoring. One of the core principles of strategic thinking for sustainability (ST4S) in strategic environmental assessment, as developed by Partidário and elaborated in various publications (e.g., 2021), is grounded in a whole-system perspective. This principle emphasizes that understanding a system's behavior requires more than merely knowing its individual elements.

Overall, Task 2.3 in the BioValue projects aims to "understand causal mechanisms in spatial planning and infrastructure development used in SEA and EIA to explore how these might be improved to enhance its role in generating transformative actions for biodiversity".

The focus in Task 2.3 is to annotate and analyze causalities in collected SEA and EIA reports:

'Activity (plan/project) → impact → significance → mitigation'

With regard to the task, the choice of a systems approach as method allows for developing and applying CLDs as a tool for capturing cause-effect relations and biodiversity mitigation hierarchy connected to spatial planning and management instruments. This approach aims to improve the making of causal

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connections in environmental assessment practice and improve and rethink mitigation to increase the transformative potential of environmental assessment instruments in spatial planning processes.

Of importance to this task is also the following data:

- Mapping the European spatial planning landscape and benchmark policy directions for biodiversity-inclusive spatial planning (from T1.1)
- Benchmark of environmental assessment instruments best practice and potentials for biodiversity considerations (from T2.1)
- Screening of economic and financial instruments in terms of their interaction with spatial planning on biodiversity (from T3.1)

In the following, we will unfold the methodological choices concerning data preparation and analysis of causalities, drafting and qualifying the CLDs.

13.1 Preparing the data for analyzing causalities

Selection of SEA and EIA reports
The first step involved the selection of SEA and EIA reports. These reports are essential as they contain detailed information about the relations between different plans/projects, biodiversity impacts, and mitigation and enhancement possibilities. The selection criteria include:

1. The reports must be of relevance to spatial planning and thus land-use changes.

2. The EIA reports must cover projects with extensive land use or land conversion
   With this criterion, cases are secured which, in terms of their geographical distribution and extent, will have a potentially significant impact on biodiversity. The criterion is met by choosing cases that are either linear infrastructure projects or projects with extensive land occupation/conversion. For projects, the BioValue projects include roads, rails, cables, photo voltaic and wind energy.

3. The SEA reports must cover plans related to spatial planning.
   Spatial planning concerns the policies and regulation of land use in a certain geography, being national, regional, or local. Spatial planning is making significant provision for biodiversity through its key role in forming societal activities and defining and setting restrictions for the use of the limited land area. The SEA reports chosen must cover either overall spatial planning or local level spatial planning and are related to land use and energy only.

4. The reports must date 5 years back at maximum.

Building causality framework
Task 2.3 aims to understand causal mechanism in spatial planning and infrastructure development used in SEA and EIA. The causalities are mapped from activity to impact to significance determination and finally to mitigation. This is illustrated in Figure 22 with a photo-voltaic project leading to tree felling in the project area significantly negative impacting roosting bats, which is mitigated through compensating measures.

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Figure 22: Illustration of the analysis of causalities. (Source: Authors model).

In the analysis each report is annotated for each step of the causality chain in Figure 22, following the approach outlined below.

Activity: The annotation of activities related to what causes the impacts. Even though there are activities that are covered by several project and plan types (e.g., land acquisition, excavation work, etc.), the annotation of reports takes place openly. This means that no predetermined categories are defined.

Impact: The BIOVALUE uses an ontology covering: Appendix IV species, red listed species, other protected species, Invasive species, Natura 2000 and Ramsar areas, protected areas, ecological connections, forest, lowland soils (peatland), wetland, water environment, habitat not protected, ecosystem, biodiversity, other.

As part of mapping the impact on biodiversity, the annotation includes an indication of the phase in which the specific impact is expected to take place. This entails construction, operation, and decommissioning.

Significance: The annotation of significance includes both positive and negative impacts, and thus follows the two directives (EC, 2001 and 2014). In addition, the BioValue project distinguishes between 'Significant', 'Non-significant' and 'Neutral' impacts. A final category is 'Unknown and negative', which applies in cases where the text in the reports is not clear about the level of significance.

Mitigation hierarchy: The mitigation hierarchy is used as a framework (see Figure 19). For clarity the BioValue project will use the term mitigation to encompass both mitigation of negative impacts and enhancement of positive impacts.

13.2 Mapping causalities

The basic data for the mapping of causalities origins from a subsection of the 200 SEA and EIA reports which was used for testing the benchmark tool developed in relation to Task 2.1 and 2.2, reported in Deliverable 2.1 extended (Vammen et al., 2022 and 2024). 69 of the 2000 reports satisfied the criteria mentioned above in 13.1.

From these reports information was extracted and registered in a spread sheet for overview. The information regarded:

- The phase of which the specific impact was expected to unfold

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- The type of impacted recipient (one or more of Appendix IV species, Other protected species, Invasive species, Natura 2000 and Ramsar areas, Protected areas, Ecological connections, Forest, Lowland soils, Wetland, Water environment, Not-protected habitats, Ecosystem, Biodiversity and Other)
- The character of the impact (Negative or positive, How the recipient is impacted, Unknown or Not relevant)
- How the significance of the impact is assessed (Significant positive, Significant neutral, Significant negative, Non-significant positive, Non-significant neutral, Non-significant negative, Un-known significance, Missing assessment of significance)
- If mitigation is reflected, and if so, which type of mitigation (Avoidance, Minimization, Restoration, Off-sets, Enhancement)
- If residual impacts were assessed

Based on the data on considerations about expected impacts, recipients and mitigations from the various types of plans and projects, the most dominant types of spatial planning situations were identified for defining the challenges to address in the CLD construction and systems analysis. This led to the four CLDs of cases of urban expansion, agricultural practices, push for renewable energy production, and expansion of infrastructure. The elements of the CLDs were further informed by the data from the SEA and EIA analysis and literature addressing these situations.

13.3 Drafting CLDs

Participatory modeling

Based on a participatory modeling approach (Perrone et al., 2020; Vennix, 1995), CLDs were created as a collaborative effort between AAU project partners and an external partner with extensive experience in systems analysis. The CLDs were initially drafted between two or more of the partners and modeling steps, assumptions and observations for each of the models were recorded along the way. Four case studies were chosen based on their relevance to current spatial planning realities as well as their applicability to the three arenas for the BioValue project. Although they do not represent the arenas one to one, they do represent spatial planning cases that can provide general insight to the arenas in different ways (as outlined in Chapter 12).

After the first draft of each CLD was initiated, each CLD was aggregated in accordance to Bureš (2017) by one of the partners and then brought into plenary again for iterative follow-up meetings and adjusted according to partner input. There were multiple iterations for each CLD. During one round of iterations, it was decided to aggregate the variables relating directly to the leverage points identified in the Biological Principles, meaning that the Biological Principles would only be represented by their identified leverage points in the CLDs related to the four cases. This fundamentally changed the structure of the CLDs such that they focused more on how the cases impact the Biological Principles through their leverage points. Leverage points (those related to Biological Principles, spatial planning and governance) were determined in plenary and informed by the leverage ranking by Meadows (1997). Mitigation and enhancement measures were mapped after the initial draft for each CLD was complete. based on data drawn from analyzed EIAs and SEAs and then presented to other partners and adjusted according to the feedback. These mitigation and enhancement measures were assigned a colored circle depending on where they fall on the mitigation hierarchy. Lastly, the pathways (arrows) between the variables were assigned a color based on ‘modules’ of impacts that relate to one another and are part of the same narrative, often sharing one or two parent variables.

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The input data for making the CLDs is a combination of the data retrieved from the causality analysis presented earlier in this section (related to T2.2) and general knowledge regarding the impacts from the exemplary cases given extensive prior experience with environmental assessment.

Assumptions and system boundaries
Before delving into the boundaries and assumptions for the individual CLDs, more general assumptions and boundaries are presented. The general boundaries that apply to all CLDs are as follows:

- The level of detail presented in the CLDs corresponds to the level of detail typically provided in environmental assessment reports. The primary reason for this is that the knowledge feeding into the CLDs stems from environmental assessment practice and the CLDs should be recognizable for practitioners and planners working with environmental assessment in practice.

- The variables and pathways are scoped to biodiversity dynamics and as such, do not represent social nor economic that are otherwise addressed in environmental assessment practice.

- The variables and pathways described are deemed to be noteworthy for biodiversity, and the CLDs do not account for insignificant impacts and impacts deemed particularly relevant for only select individual cases.

- The impacts described are focused on those considered to be permanent and do not account for temporary impacts from, e.g., those only temporarily relevant during the construction phase.

Conversion of agricultural areas
For the first exemplary case, the activity being mapped is the construction and operation of PV parks. These PV parks are assumed to be constructed on agricultural land because this is a common development within spatial planning and because the case's purpose is to show the biodiversity value that can be harvested when converting agricultural land. This excludes the fact that PV parks can be constructed on other types of areas and that other types of projects (besides PV parks) can also result in the conversion of agricultural land. Traffic from construction has been scoped out of the CLD but can be found in the expanded version presented in the annex. This was to preserve the focus on the act of converting agricultural land to PV parks but is still recognized as having an impact on species (of all protection levels) during the construction phase. This is also due to a boundary on long-term and permanent impacts, rather than the temporary ones resulting from the construction phase. The risk of human intervention has been scoped out and is not a consequence that can be tied to the conversion from agricultural land. Lastly, the assumption is made that all agricultural land can be converted to other purposes, effectively ignoring the categorization of "special agricultural land", which, at least in a Danish context, solely designates that area to agriculture. The CLD does not account for this.

Habitat conversion
The land-take CLD was originally made from a specific case where the establishment of housing would draw upon the protected buffer area running alongside a river. It was decided to make the case broader to represent more generally the consequences of converting protected areas to urban development practices and can thereby be applied to many different cases. This CLD on land-take of protected areas is therefore also an embedded part of the case of PV park construction, if the PV park was to be built on protected, rather than agricultural areas. It is also an embedded part of the linear infrastructure, seeing as road/railway development often trespasses onto protected sites, requiring dispensation. It should also be noted that dispensation was not found explicitly in the causality data from the environmental assessment reports. It was nevertheless determined significant to model as dispensation is generally speaking a common practice when wanting permission for urban development on protected areas.

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Habitat fragmentation

Temporary consequences of the construction of linear infrastructure, such as removing forest to allow access for vehicles that will be replanted later, was not included in the CLD as it focuses on the more permanent impacts (see general boundary described above). Whereas they are important for environmental assessment practice to account for, they are outside the scope of the CLDs in this report. After the initial draft was made, it was decided to focus solely on the concept of fragmentation and the CLD was condensed accordingly. And just as Habitat conversion feeds into Habitat fragmentation, then Habitat fragmentation also becomes and input into Habitat conversion, claiming that the conversion of habitat contributes to the fragmentation of those habitats. Fragmentation is therefore not limited to linear infrastructure.

New habitat development

The CLD was originally made with the assumption that new forest was being planted on agricultural land. The specification of this was removed when condensing the CLD to biodiversity impacts from afforestation, thereby omitting the spatial planning decision of which land is to be converted. In a Danish context, it can nevertheless be assumed to be agricultural land, which effectively creates a link to the subsystem of land-use change from agricultural land. Additionally, recreational use was also omitted from the final CLD, as a result of omitting social impacts. Negative shadow effects emerged from the analyzed SEA and EIA reports as a consequence of planting forests but was considered to be too case-specific and was therefore omitted from the CLD.

Biological Principles 1 and 2

The CLDs for the Biological Principles have focused solely on the fundamental biological relations as described by Petersen et al. (2024) and therefore do not include human factors (e.g., actions, decisions) that could interfere.

13.4 Loop analysis and identification of leverage points

After the CLDs for the Biological Principles and the cases were finalized, reinforcing and balancing loops were identified, i.e. closed chains of causal connections where an initial change in a variable eventually feeds back to influence the same variable, either directly or indirectly (Sterman, 2000). Strengths, polarities and delays of each loop were assessed to gain an understanding of the systems' structure and resulting behavior over time, and the most dominant loops, which drive the systems behavior, were identified.

After understanding the role of the feedback loops, it was determined which loops should be strengthened, weakened, or introduced to achieve desired outcomes, and the relevant leverage points were set (Meadows, 1999). This step also informed the choice of enhancement and mitigation measures suggested in the various cases.

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13.5 Bringing CLDs and deliverable 2.3 to practice

Following this report's finalization is a collaborative and iterative phase among project partners and each arena.

The methodology for leveraging existing CLDs in the BioValue arenas will involve using these developed tools and related knowledge to inform planning processes within the arenas of Mafra Municipality, Fersina River and Mecklenburg-Vorpommern. The focus will be on applying these insights collaboratively to enhance the transformative potential of SEA and EIA in spatial planning.

The methodology and process involve:

1 Exploration and familiarization
- Knowledge sharing workshop to familiarize partners and arenas with the developed CLDs and their components.
- Ensure an understanding of the key variables and feedback loops represented in the CLDs, particularly those related to BP1 (Habitat area and quality) and BP2 (connectivity and source-sink dynamics).

2. Collaborative exploration
- Scenario discussions with facilitated discussions around different land use and conservation scenarios using the CLDs. Hereunder exploration of potential outcomes of various planning decisions and interventions.
- Use CLDs to trace impact pathways to explore how changes in one part of the system (e.g., urban development and habitat restoration) affect biodiversity.

3. Informing EIA, SEA and spatial planning processes
- Integrating insights with an incorporation of insights from the CLDs into EIA, SEA and planning processes to evaluate potential impacts of proposed projects, plans and policies.
- Use CLDs to highlight critical variables and feedback loops that should be considered in environmental assessments, ensuring a comprehensive and proactive evaluation of environmental impacts.

4. Strategic planning and decision support
- Policy and planning recommendations based on CLD insights that promote habitat connectivity, quality, and resilience.

To support the further development of CLDs, meetings with each arena will be held.

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Annexes

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Annex I Example of CLD for population dynamics

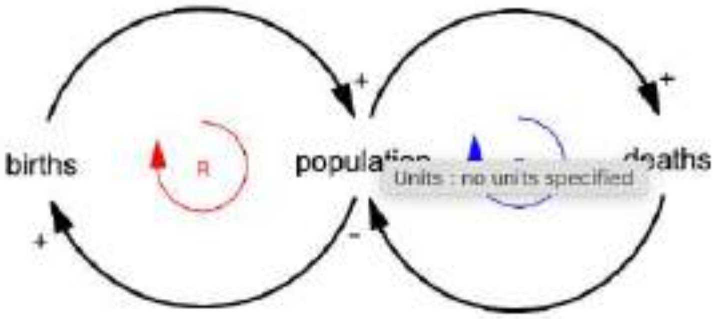

Figure 23: CLD illustrating population dynamics (adopted from Sterman 2000).

To illustrate how to read a CLD, we will use the example of population dynamics (fig.4), focusing on the core elements: Population, Birth Rate, and Death Rate. In the example of population dynamics, CLDs help in understanding how population size is regulated by births and deaths, providing a holistic view of the system's behavior. The step-by-step analysis is as follows:

1. Identify Variables and Initial Relationships
   - Population: The number of individuals in a given area.
   - Births: The number of individuals being born.
   - Deaths: The of individuals that die.

2. Determine Direct Influences
   - Population to Births (+): The larger the population, the more births.
   - Population to Deaths (+): The larger the population, the more deaths

3. Construct Feedback Loops
   - Reinforcing Loop (R1): Population Growth
   - Population → Births (+) → Population (+)
     - This loop indicates that an increase in population leads to more births, which further increases the population, creating a reinforcing (positive) feedback loop.
   - Balancing Loop (B1): Mortality Regulation
   - Population → Deaths (+) → Population (-)
     - This loop shows that as the population increases, the number of deaths increases, too, which in turn reduces the population, creating a balancing (negative) feedback loop.

4. Interpreting the CLD
   - Reinforcing Loop (R1): This loop demonstrates the potential for exponential growth in the population if unchecked by other factors.
   - Balancing Loop (B1): This loop introduces a natural regulatory mechanism where increased population size can lead to more deaths, thus preventing unlimited population growth.

If the number of births and deaths is the same, the population is kept ich check. If the number of births exceeds the number of deaths, the population will grow. If the number of deaths exceeds the number of births, the population will decline.

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Annex II Complete list of feedback loops in the combined CLD of the Biological Principles 1&2

Reinforcing feedback loops

1. R (2): source: donor population -+> exchange of individuals -+> source: donor population
2. R (3): persistence of ecosystems* -+> quality of area -+> number of species* -+> persistence of ecosystems*
3. R (3): persistence of ecosystems* -+> quality of area -+> number of habitats -+> persistence of ecosystems*
4. R (3): number of species* -+> need for habitat -+> area for habitat -+> number of species*
5. R (3): source: donor population -+> exchange of individuals -+> sink: recipient population -+> source: donor population
6. R (6): persistence of ecosystems* -+> quality of area -+> number of species* -+> need for habitat -+> area for habitat -+> number of habitats -+> persistence of ecosystems*
7. R (8): persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> source: donor population -+> persistence of metapopulation -+> number of species* -+> persistence of ecosystems*
8. R (8): persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> persistence of metapopulation -+> number of species* -+> persistence of ecosystems*
9. R (8): persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> genetic diversity* -+> persistence of metapopulation -+> number of species* -+> persistence of ecosystems*
10. R (8): number of species* -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> source: donor population -+> persistence of metapopulation -+> number of species*
11. R (8): number of species* -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> persistence of metapopulation -+> number of species*
12. R (8): number of species* -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> genetic diversity* -+> persistence of metapopulation -+> number of species*
13. R (9): persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> source: donor population -+> persistence of metapopulation -+> number of species* -+> persistence of ecosystems*
14. R (9): number of species* -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> source: donor population -+> persistence of metapopulation -+> number of species*

Balancing feedback loops

1. B (3): need for habitat -+> area for habitat -+> number of habitats --> need for habitat
2. B (6): persistence of ecosystems* -+> quality of area -+> number of habitats --> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems*
3. B (9): local extinction -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> source: donor population --> local extinction
4. B (9): local extinction -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population --> local extinction
5. B (9): individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> genetic diversity* --> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat

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6. B (10): local extinction -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> source: donor population --> local extinction
7. B (10): local extinction -+> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> source: donor population --> local extinction
8. B (10): local extinction -+> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population --> local extinction
9. B (11): local extinction -+> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> source: donor population --> local extinction
10. B (12): local extinction -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> source: donor population --> local extinction
11. B (12): local extinction -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population --> local extinction
12. B (12): persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> genetic diversity* --> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems*
13. B (13): local extinction -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> source: donor population --> local extinction
14. B (13): local extinction -+> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> source: donor population --> local extinction
15. B (13): local extinction -+> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population --> local extinction
16. B (14): local extinction -+> need for genetic diversity -+> need for minimum viable population size -+> individual species' need for habitat -+> need for habitat -+> area for habitat -+> number of species* -+> persistence of ecosystems* -+> quality of area -+> number of habitats -+> connectivity -+> exchange of individuals -+> sink: recipient population -+> source: donor population --> local extinction

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