Interreg
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PlanToConnect

GBI-network: Land use conflicts for RE production and other threats

Province of Sondrio

Mapping report outlining GBI network elements and areas of land use conflicts for renewable energy production and other major developments that may threaten GBI connectivity function

This project is co-funded by the European Union through the Interreg Alpine Space programme.

PlanToConnect

GBI-network Land use conflicts

Mapping report outlining GBI network elements and areas of land use conflicts for renewable energy production and other major developments

Activity 2.4 Case Studies 3rd step: Identify unsuitable locations/mitigation measures for impact assessment of renewable energy systems and other major developments that may threaten GBI connectivity function

Fondazione Politecnico di Milano

In collaboration with:

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EXECUTIVE SUMMARY

The PlanToConnect project aims to develop and test an Alpine spatial planning strategy for ecological connectivity in collaboration with stakeholders in pilot areas. The project focuses on adapting spatial planning systems and territorial policies to enhance ecological connectivity. As part of this initiative, Fondazione Politecnico di Milano, with the scientific support of the LabPPTE of the Department of Architecture and Urban Studies (DAStU), Politecnico di Milano, is conducting a case study in the province of Sondrio, located in the northern Lombardy region.

The GBI network design for the pilot region has been structured around three main strategic frameworks, which serve as the foundation for integrating the GBI into various planning instruments at different scales. This report (D2.4.1) examines land-use conflicts arising from renewable energy developments and other urban transformations that may threaten the connectivity of the GBI network. Specifically, the report describes and assesses the potential impacts of these infrastructures on the GBI network, maps the land-use conflicts caused by these transformations and suggests criteria for unsuitable locations for different types of infrastructure. Furthermore, it proposes possible compensation measures to mitigate the impacts of these developments on ecological connectivity.

For the case study in the province of Sondrio, due to the lack of data on planned renewable energy projects and the principle that all new land-use transformations may significantly impact the ecological and ecosystemic value of the territory, all planned transformations were considered as potential threats to ecological connectivity. A thorough analysis was conducted to identify unsuitable areas for future transformations based on the strategic frameworks defined in the Multifunctional GBI project. The outcome of the document leads to the identification of unsuitable areas, designated as off-limits for development; and critical areas, where transformations can be allowed under compensatory procedures defined in the conclusive chapter.

REPORT

1 Introduction

The PlanToConnect project aims to develop and test an Alpine spatial planning strategy for ecological connectivity in cooperation with stakeholders in pilot areas. Proposals for the adaptation of spatial planning systems and territorial policies will be developed.

As part of the PlanToConnect project, Fondazione Politecnico di Milano, with the scientific support of the LabPPTE, Department of Architecture and Urban Studies of the Politecnico di Milano, is conducting a case study on the integrated planning of a Multifunctional GBI (Green and Blue Infrastructure) connectivity network in the pilot area for the province of Sondrio, in the north side of Lombardy Region. The project is structured around an analysis of the ecosystem performance of the provincial area, particularly the current degree of ecological connectivity and the fragmentation of ecological corridors. The objective is to select priority areas for the protection and enhancement of soils with high multisystemic capacity and to define a strategic design for a multifunctional green network integrated with the broader transalpine ecological connectivity network. The identification of key anthropogenic threats to connectivity functions and biodiversity preservation will guide the definition of the main challenges that the Green and Blue Infrastructure will need to address. The design of a GBI network for multifunctional connectivity in the pilot region has been developed and described in the D2.3.1, where 3 main strategic frameworks are identified. The frameworks set the basis for the development of the GBI design and its integration and implementation into the planning instruments at different scales.

This report (D2.4.1) focuses on the land-use conflicts arising from renewable energy facilities and the other urban transformations that may threaten the GBI network for connectivity in the pilot region. The objectives are:

- to describe and to assess the potential impacts of renewable energy infrastructures or other infrastructures that may threaten the GBI network for connectivity,
- to propose evaluation criteria for unsuitable locations for the various types of infrastructures,
- to map the land use conflicts for threatening transformations
- to suggest possible compensation measures.

This report covers all spatially relevant infrastructures that have already had a negative impact on ecosystem asset and ecological connectivity (pressures) as well as those that pose a threat to connectivity in the future (threats)[1]. In the case study of the province of Sondrio due to the absence of data concerning the anticipated development of renewable energy sources and in accordance with the principle that any intervention or new urbanisation of the land may result in substantial impacts on the ecosystem and ecological value of the territory, it was decided to consider all transformative forecasts and regard them as posing a threat to ecological connectivity.

[1] Pressures are factors that have affected habitats and species, threats are factors that are anticipated to be likely to have an impact in future (European Environment Agency 2020).

2 Pilot region: Province of Sondrio

The Province of Sondrio represents the area of interest as a pilot case for the PlanToConnect project due to its high landscape-environmental values, which coexist with elements of fragility and pressure caused by a variety of factors. Moreover, the initiation of the process to update the Provincial Territorial Coordination Plan (PTCP), in force since 2010, provides a key opportunity to test the potential impacts of the project within territorial planning tools, particularly concerning the construction of a multifunctional green and blue infrastructure aimed at strengthening ecological connectivity and preserving the rich environmental and landscape heritage of the area. Several natural elements contribute to defining the rich and diverse biodiversity of the province, such as the watershed of the first stretch of the Adda River, the lateral valleys, and the mountainous slopes forming part of the Alpine arc. Sondrio is the only province in Lombardy with an entirely mountainous territory, covering over 3,000 km², with nearly half of it located above 2,000 meters in elevation, reaching the top elevation on the Bernina Mount (4050 mts). The Valtellina is further characterized by a widespread historical and cultural heritage and unique landscapes, which enhances the area's tourism appeal, primarily linked to outdoor recreational and ski and alpine sports activities. In this context, the project aims to develop a multifunctional green and blue network design based on an assessment of the territory's ecosystem performance, identifying areas of high value and critical issues.

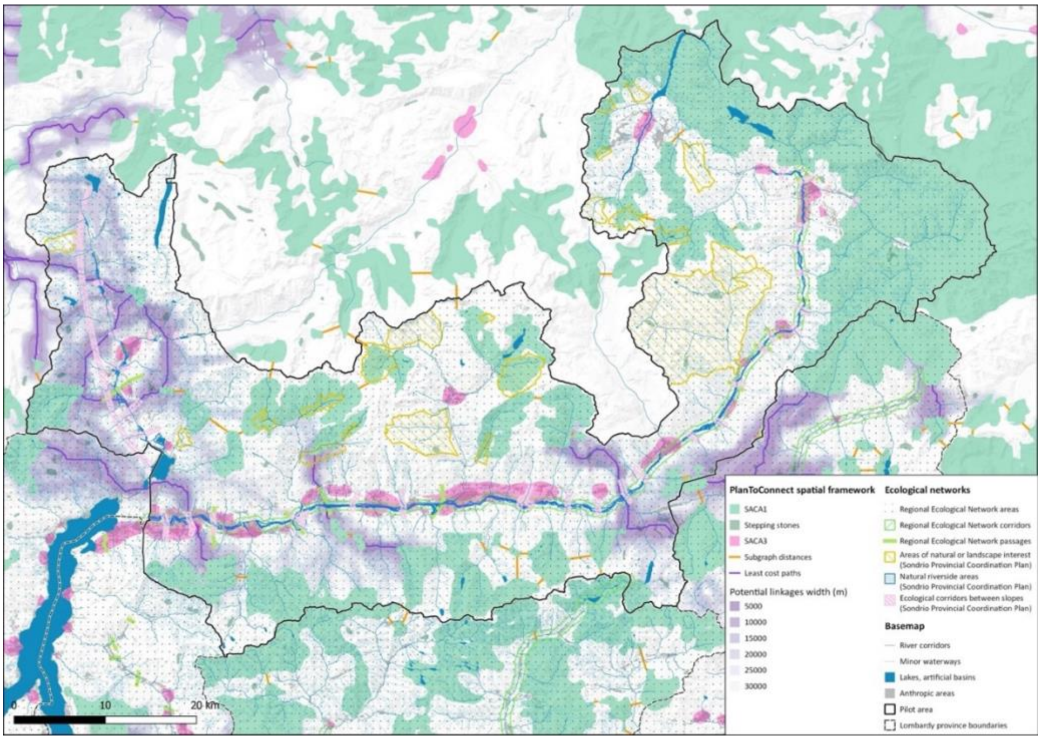

Figure 1 - Overview- Province of Sondrio

3 Methodological steps

The Green Blue Infrastructure (GBI) project for the Province of Sondrio is grounded in the principle of multifunctionality, guiding the preservation and respectful utilization of the area's rich natural, ecological, and ecosystemic heritage. The definition of the infrastructure is currently underway and involves several steps that inform its characterization and delineation. Initially, an assessment of seven ecosystem services (ESs) was conducted to evaluate the current delivery of ecosystem benefits dictated by soil characteristics and natural components. Subsequently, a composite analysis of these seven values was performed, determining the multisystemic value of the province and identifying areas that exhibit high multifunctionality as well as those with low ecosystem quality.

This level of information was cross-referenced and overlaid with previously analyzed data, including Strategic Alpine Connectivity Areas (SACA), regional and provincial ecological network data, and multifunctional elements from the Regional Landscape Plan (PPR). The overlay of these elements, combined with a hotspot analysis derived from the multisystemic assessment, facilitated the identification of key classes that will shape the core structure of the multifunctional infrastructure. These classes are characterized by three primary attributes: conservation, regeneration and multifunctionality.

Table 1 - General Working steps

Working Step	Description
1	**Compilation of the protected areas within the Sondrio province**
	In a first step, all significant core areas within Sondrio province are compiled and briefly described.
2	**Compilation and analysis of GBI elements within the area (connectivity evaluation)**
	In a second step, all GBI elements (based on the categories of CORINE Land Cover 5 ha CLC5 (2018) within the corridor are listed and summarised according to the main categories: • Natural/ Semi-natural grassland

Working Step	Description
	• Sparsely vegetated areas • Forests and other wooded lands (shrubs, hedges, trees) • Water bodies (flowing and standing water) • Wetland (marshes, peatbogs)
3	**Definition / refinement of objectives for ecological connectivity**
	Based on the evaluation of spatial data within the selected corridor the objectives for ecological connectivity will be defined in more detail.
4	**Compilation and analysis of regional and local data**
	The analysis and mapping of regional and provincial data concerning ecological networks, as well as other landscape elements with recreational and multifunctional components, contribute to the understanding and refinement of corridors, gaps, and areas of high natural and landscape value. These findings are essential for identifying which features should be included and safeguarded during the definition of the project infrastructure.
5	**Barrier Analysis (based on D 1.2.1 and 1.3.1)**
	Depending on whether the connectivity of structures or species is being considered, there are very different threats or barriers in the landscape. In a further step possible threats and barriers in the selected corridor are compiled and analysed
6	**Ecosystem Services Mapping & Assessment**
	The mapping and analysis of the seven selected ecosystem services for the project area are conducted to understand the ecological qualities inherent to the territory. This phase is characterized by two steps: the first involves data collection and modeling, followed by the comprehension, visualization, and interpretation of the models.

Working Step	Description
7	**Multisystemic Composite Value Assessment**
	The seven layers of ecosystem information are overlaid and summed to create a map of composite multisystemic values. This step is particularly valuable for assessing the overall multifunctional capacity, enabling the identification of areas with high multifunctional potential as well as those that are deficient and degraded.
8	**Overlaying process and initial GBI classes' definition**
	The map of composite values is interpreted and refined by focusing solely on the highest composite values (Hotspot analysis), which will define the framework of the Green and Blue Infrastructure (GBI). At this stage, the newly generated mapping begins to interact with previously analysed local, regional, and interregional data, allowing for the identification of similarities and differences among them.
9	**Multifunctional GBI classes characterization**
	The hotspot analysis generates the structure of the GBI infrastructure, which is then enriched and integrated with other elements essential for the network design in the pilot case. This new overlay, incorporating both natural and cultural elements, leads to the identification of three main categories: conservative, multifunctional, and regenerative. These three frameworks, along with their respective overlays, establish the strategic framework of the network project.
10	**Implementation process and definition of guidelines for the integration of the GBI in the planning processes**
	The definition of the technical implementation aspects of the GBI multifunctional project is the conclusion of the design phase. This phase goes hand in hand with the design of the infrastructure, as the strategies, design and actions must be closely linked to the geometries and land use mechanisms of spatial planning

Working Step	Description
	tools in order to find a possible real application. Additionally, guidelines for GBI implementation will be provided to allow local administration to benefit from our research.

3.1 Description of the approach/ working steps

The identification process of the existing threats to ecological connectivity and the preservation of natural and landscape heritage within the project area began with an analysis of municipal and provincial planning documents (PGT and PTCP). These plans were used to identify regions classified as threats, not only for future projects—where preventive measures are still feasible—but also for existing ones, often stemming from dynamics associated with the historical traditions of tourism and industry, which have been primarily concentrated in the lower valley.
Specifically, as detailed later in the document, the main threatening elements identified in this document include high-flow transport infrastructure, dispersed settlements and infrastructure, ski domains, degraded and abandoned areas and forecasted transformation related to residential, tourism, productive and tertiary functions.

The identification of existing and planned threats also led to the assessment of renewable energy installations, analyzing their potential impact on the multifaceted connectivity objectives of the GBI project. This analysis proved more complex than the previous one, as the regulation linking renewable energy development to environmental value threats is relatively recent.
The analysis of renewable energy installations has been carried out considering the current provisions of the National Decree on Suitable Areas, published in July 2024, which mandates that the Regions adopt or restate national guidelines at the regional level. In December, the Lombardy Region published the Decree "Approval of New Regional Guidelines for the Authorization of Installations for Electrical Energy Production from Renewable Sources (RES)," following updates to national legislation in this field. In addition to this decree, other technical and legal documents were reviewed.
A major challenge encountered was the geo-referenced mapping and forecasting of renewable energy installations at the provincial level (and thus at the scale of our pilot case). In fact, the most recent documents addressing these issues are the 'Energy Plan' and the 'Water Plan' from 2010 and these are just available in the PDF version.

The key issues analyzed in preparation for this document pertain to renewable energy infrastructures and the associated natural entities that they may endanger. The analyses conducted allowed us to determine that the most significant threat associated with renewable energy infrastructures is the numerous presence, both existing and planned, of small- and medium-sized hydroelectric plants within the provincial territory. Additionally, three biomass production plants were identified (as of 2005: Tirano, Sondalo, Teglio, with a planned plant in Caterina di Valfurva). Photovoltaic installations are widespread in the Lombardy Region starting from the early 2000s, but no geo-referenced or descriptive data on these installations are available.

An outcome document of the PlanToConnect project (report D1.3.1) conducted a comparison and analysis of anthropogenic activities as threats to ecological connectivity across the Alpine region. The analysis of individual pilot cases resulted in this report, which primarily addresses the location and implementation of Renewable Energy (RE) installations. Regardless of national regulations, certain shared constraints apply across the entire Alpine region, particularly regarding protected areas and morphological conditions, as outlined below. Approximately 28% of Alpine land is designated as Protected areas by law, including national parks, biosphere reserves, and Natura 2000 sites. Consequently, RE development is either restricted or only feasible to a limited extent in these zones (Alpine Convention 2015/2016).
In terms of RE types and their potential threat to ecological connectivity, the following observations have been made.
Traditional energy sources, such as hydropower and forest biomass, are well-established in the region and continue to contribute significantly to RE production, while other sources, including solar, wind, biogas, and agricultural biomass, are increasingly gaining importance (Hastik et al. 2016). Most hydropower potential in the Alps has already been exploited, and further development must be approached with caution, as new projects may have adverse impacts on river ecosystems and incur substantial ecological compensation costs (Hastik et al. 2016). Wind energy generation in the Alps is predominantly concentrated on ridges and mountain crests, with limited expansion potential due to the region’s average wind yield in comparison to coastal areas, as well as the presence of protected areas (Alpine Convention 2015/2016). The potential for solar energy varies across the region, with Italy and France benefiting from higher solar radiation owing to their southern exposure (Alpine Convention 2015/2016). Forest biomass continues to be a significant renewable energy resource, although its available potential is largely utilized. Moreover, forestry practices must increasingly emphasize soil preservation and nutrient management (EU 2022/2448). In comparison, solar energy presents the greatest expansion potential, followed by wind

energy and hydropower. In some regions, agricultural biomass may serve as an additional energy source (Hastik et al. 2016).
The expansion of RE in the Alps poses conflicts between energy production and nature conservation, due to the region's fragile ecosystems, high biodiversity, and mounting land use pressure (Hastik et al. 2016). Additionally, the challenging topography and difficult accessibility in mountainous areas require the development of appropriate infrastructure, such as roads, power lines, and construction sites, which could further exacerbate landscape and environmental impacts. These considerations must be taken into account in future energy development planning.

Taking into account the previously mentioned analyses and considerations, the Multifunctional Green and Blue Infrastructure project aims to prevent emerging threats and mitigate or compensate for existing threats. Three strategic frameworks and one additional conservative layer have been identified to guide the project: conservative, multifunctional and regenerative. For each framework, strategic lines are defined based on the ecological and ecosystem quality of the area and its role within the project. In particular, within the conservative framework, no new development will take place in order to maintain the high natural value of these areas and prevent further urbanisation and anthropogenic activity. In multifunctional and regenerative areas, the relocation of transformations to already urbanised (abandoned and degraded) areas will be encouraged wherever possible. Where new development is deemed absolutely necessary, compensatory measures will be put in place to maintain or improve environmental quality. Within these areas, restoration areas have been identified and will be treated separately from the frameworks under which they fall, through careful de-fragmentation efforts and the implementation of measures aimed at ecological and natural restoration. In this context, any planned projects will be relocated. With regard to existing threats, appropriate mitigation measures will be proposed to minimise the anthropogenic impact on the rich natural and environmental heritage of the Province of Sondrio.

3.2 Data used

The table presents the plans, regulations and elaborations that proved useful in the drafting of the document and in parallel with the achievement of the project. The plans and regulations relate to the different spatial planning scales instruments, ranging from national to provincial. With regard to the elaborations, data from the project PlanToConnect were drawn from both the comparative reports of the various pilot cases and own elaborations related to the realisation of the project for the Province of Sondrio.

Table 2 - Overview of local or regional data used

Data	Source	Description
Sistema delle Aree Protette Lombarde (LR 30 novembre 1983 n. 86)	Regione Lombardia	Lombardy's heritage of natural, historical and cultural riches to be protected, promoted and valorised
Piano paesaggistico regionale (PPR)	Regione Lombardia	Regional Landscape Plan
Rete ecologica regionale (RER)	Regione Lombardia	Regional Ecological Network
Provincial Ecological Network (REP)	Provincia di Sondrio	Provincial Ecological Network
Land use Land Cover (DUSAF 7)	Regione Lombardia	Regional Land use classification
Foreseen Transformations	Regione Lombardia	Municipal Foreseen Transformations
Decreto Aree Idonee	Ministro dell'Ambiente e della Sicurezza Energetica (MASE)	National decree on the identification of suitable and unsuitable areas for the installation of renewable energy plants
Linee guida impianti produzione energia elettrica da fonti rinnovabili	Regione Lombardia	Regulation of administrative regimes for the production of energy from renewable sources at regional level
Strategic Alpine Connectivity Areas (SACA)	ALPBIONET2030	Classification of the alpine and EUSALP area in three types of categories offering the possibility to better target actions in favor of ecological connectivity
Threats report on alpine ecological connectivity, renewable energies and upcoming spatial needs	PlanToConnect (report D1.3.1)	Identification of major emerging threats posed to GBI ecological network integrity and connectivity function, focusing on increased renewable energy production
Multifunctional GBI Strategical frameworks	FPM (D2.3.1_final_FPM)	Identification of three main strategical framework to maintain, valorise and enhance the system of ecosystem, natural, cultural values of the pilot area

4 Major pressures and threats to ecological connectivity

Pressures are factors that have affected habitats and species, threats are factors that are anticipated to be likely to have an impact in future (European Environment Agency 2020).

Referring to threats already identified in the documents D1.3.1 and D2.3.1.

4.1 General threats to GBI ecological networks posed by infrastructure and land uses

The table below lists infrastructures and land uses analysed in report D1.3.1 and assesses their impact on connectivity across the landscape. A distinction is made between structural and functional connectivity (see report D1.3.1).

Table 3 - Infrastructures and land uses with their impact on connectivity

Sector	Type of infrastructure/ Land use	Comments on Connectivity
Renewable energy	Hydropower - hydroelectric reservoir (dam)	These facilities, which are largely present in the local area, have a high impact on structural and functional connectivity, due to the occupation of generally extensive land and barrier and fragmentation effects. Water purification and treatment interrupt the migratory routes of some fish and hinder the natural transport of debris material in our streams and rivers. Further downstream, there is thus a lack of gravel and sand, crucial foundations for many habitats and for the reproduction of numerous species.
	Hydropower - Run-off-river power plants	In contrast with the previous one, the run-off-river power plants have a lower impact on structural connectivity because of minimal land take. On the other side, similarly the the dams, these have high impact on functional connectivity because of barrier/ fragmentation effects in the water body.
	Solar Power - Photovoltaics: Ground-mounted solar panels	The impact of photovoltaic installations varies considerably depending on their location and size. Installations located in already urbanised areas do not contribute to a significant threat to ecological connectivity, either structurally or functionally, as they are already sealed and usually not affected by the flow of ecological corridors. On the contrary, despite their low soil consumption at ground level, plants located on permeable surfaces contribute significantly (proportionally to the size of the project) to habitat loss and to functional connectivity. In fact, they can disrupt the habitats of many species by creating barriers to movement and ecological traps through reflected light. For this reason is important to avoid high-value agricultural land and to implement setbacks from water bodies and forests to prevent habitat fragmentation.

Sector	Type of infrastructure/ Land use	Comments on Connectivity
	Bioenergy - Biomass	Biomass production facilities tend to have a low impact on structural connectivity due to their low land use. In terms of functional connectivity, different impacts are depending on the scale of production. In fact, biomass production can have a negative impact on soil quality, biodiversity and habitats in the area if it is long term and of significant size. It is important to verify the source biomass sustainably to prevent deforestation and ensure carbon neutrality.
Energy sector as a whole	Transmission of electricity High voltage transmission line	Despite the significant challenges posed by the presence of high-voltage lines, the Province of Sondrio has been taking proactive measures to mitigate these issues. Recognising the area's scenic and environmental value, they have undertaken a project to optimise the high-voltage network. Great interest in minimizing forest clearing and fragmentation has involved the strategic burial of numerous lines and the demolition of certain land lines.
Transport	roads/ highways	Mobility infrastructure has a high impact on structural and functional connectivity due to extensive land use, barrier effects, wildlife mortality from traffic, and impacts from noise, dust and pollutants.
Transport	railway	Rail infrastructure has a high impact on structural and functional connectivity due to extensive land use, barrier effects, wildlife mortality from traffic, and impacts from noise, dust, pollutants and vibrations.
Urban /industrial development/	Urban/ industrial development/ forescasted urban trasformation	Urban, industrial and other settlements have a high impact on structural and functional connectivity due to the occupation of land (especially vacant land) causing loss of habitat and ecosystem value. They also cause barrier effects to ecological corridors, noise and air pollution. Particular attention in our case is given to forecasted urban transformations, where new urbanisation could further worsen ecological connectivity.
Ski infrastructure	Urban development	High impact on both structural and functional connectivity because of the sparse and high-altitude location of these infrastructures. Not only the infrastructure itself causes habitat loss, and fragmentation but also the attractivity of these facilities produce a lot of environmental and noise pollution.

4.2 Definition of relevant infrastructures

As outlined in report D1.3.1, the potential environmental impacts of infrastructure depend on its size and design. Therefore, it is first necessary to identify which types of infrastructure generally exert pressure on or pose a threat to ecological connectivity and are relevant for spatial planning. The key question is whether threshold values exist for projects beyond which significant negative environmental effects can be assumed.

The EU Environmental Impact Assessment (EIA) Directive establishes criteria for determining which projects require an EIA, providing a reference point for assessing the spatial planning significance of different types of infrastructure. However, the directive does not specify relevance thresholds for all project categories. EU Member States have the authority to further define the necessity of an EIA or a preliminary environmental impact assessment, either on a case-by-case basis or by establishing specific criteria such as project location, size, or type.

In the Italian context, Legislative Decree 152/2006 and its subsequent amendments (Annexes I and I-bis), which align with EU regulatory updates, serve as the primary legal framework considered for drafting this section. As highlighted in this document, when assessing a project's potential impact, it is essential to consider some crucial aspects in order to define its overall resonance in the territory:

- *Project Scale and Design*: The overall dimensions and conceptual framework of the project.
- *Cumulative Effects*: The combined impact of the project with existing or approved developments.
- *Use of Natural Resources*: The consumption of soil, land, water, and biodiversity.
- *Waste Generation*: The production and management of waste materials.
- *Environmental Pollution and Disturbances*: Potential emissions and other forms of environmental impact.
- *Risk of Major Accidents and Disasters*: Including those linked to climate change, based on current scientific knowledge.
- *Human Health Risks*: Such as water contamination or air pollution.

Additionally, the environmental sensitivity of the project location must be evaluated, taking into account the land use, the natural resource availability and regeneration capacity together with the ecological and environmental quality and specificity of the area.

The potential environmental impacts' assessment should also take into account the transboundary nature, intensity, complexity, probability, duration, frequency, and

reversibility of the impact, as well as its cumulative effect in combination with other existing or approved projects and the feasibility of effective mitigation measures.
Environmental reports accompanying plans and programs subject to strategic environmental assessment must include a description of their objectives and their relationship with other relevant plans, an analysis of the current environmental state and its likely evolution without implementation, and an evaluation of the environmental, cultural, and landscape characteristics of affected areas. Additionally, existing environmental issues must be identified, particularly those related to areas of ecological, cultural, or landscape significance, such as Special Protection Areas for the conservation of wild birds and Sites of Community Importance for habitat and species protection, as well as agricultural zones of high-quality production.
The reports should also address relevant international, EU, and national environmental protection objectives and how they have been considered in the planning process. A comprehensive assessment of potential significant environmental impacts, including effects on biodiversity, human health, climate factors, soil, water, air, material assets, and cultural heritage, must be conducted, taking into account direct, indirect, cumulative, and synergistic effects over the short, medium, and long term, as well as their temporary or permanent, positive or negative nature.
Furthermore, the reports must outline measures to prevent, reduce, and compensate for significant adverse environmental effects, justify the selection of alternatives and the evaluation methodology used, and discuss any challenges encountered in data collection. Provisions for monitoring and controlling environmental impacts should also be detailed, specifying data collection methods, impact assessment indicators, reporting frequency, and corrective actions. Finally, a non-technical summary must be included to ensure accessibility of information.
The following table shows the project types that are considered to be spatially relevant and thus may have negative impacts on the environment and connectivity.

Table 4 - Identification of projects thresholds for spatial planning taken from Dgls. 152/2006 and following integrations (Attachments I, Ibis)

	Relevance for spatial planning
Hydroelectric power plants	Concession capacity exceeding 30 MW, including dams and reservoirs directly serviced

	Relevance for spatial planning
Wind power plants for electricity production	Exceeding a total capacity of 30 MW, calculated on the basis of the project under assessment alone and excluding any plants or projects located in contiguous areas or having the same centre of interest or connection point and for which an environmental impact assessment is already underway or an environmental compatibility decision has already been taken
Photovoltaic systems for electricity production	- Exceeding a total capacity of 10 MW, calculated on the basis of the project under consideration exclusively, excluding any installations or projects located in contiguous areas or having the same centre of interest or the same connection point and for which an environmental impact assessment has already been carried out or a decision on environmental compatibility has already been issued. - Photovoltaic plants with a capacity of more than 25 MW in areas classified as suitable (Article 20 of Legislative Decree no. 199 of 8 November 2021); photovoltaic systems with a power exceeding 30 MW installed on the ground in areas and zones for industrial, artisanal and commercial use, as well as in landfills or closed and reclaimed landfills, or in plots or parts of quarries that cannot be further exploited;)
Biogas production	Production of biofuels and advanced biofuels, biomethane and advanced biomethane (including upgrading of biogas and production of BioLNG from biomethane), syngas, non-biological renewable fuels (hydrogen, e-fuels), recycled carbon fuels.
District heating/district cooling networks	Transmission line with a voltage of 110 kV or more
Railway trunks	Referred to railway trunks for long-distance traffic
Motorways and main suburban roads; - suburban roads with four or more lanes or upgrading existing two-lane suburban roads to four or more lanes	Referred to mobility infrastructures of at least 10 km uninterrupted length

4.3 Existing pressures and expected major threats in the pilot region

In summarizing the analysis of major existing and planned threats within the pilot area, the significant lack of updated data on renewable energy plants has impacted our ability to accurately map these facilities and appropriately integrate them into the GBI strategic framework.

The available data, presented in the map below (Figure 1), pertains to plants that were either operational or planned as of 2023. The primary facilities identified in the dataset include combined heat and power plants, water purification facilities, waste treatment plants, and hydroelectric stations. However, we lack confirmation on whether these facilities are still operational, whether the planned projects have been realized, or if other facilities have been introduced in local plans since then.

The legend has been divided into existing threats, which include urbanized soil (for the period 1999-2021), mobility infrastructure, existing facilities, ski infrastructure and degraded areas, and planned threats, which consist of transformation areas and planned facilities. Planned areas have been deliberately shown in a lighter colour as, in theory it would be possible to positively influence planning decisions through the Multifunctional Green and Blue Infrastructure Project. The aim is to relocate proposed developments in ecologically unsuitable areas that threaten ecological connectivity or, where relocation is not possible, to implement appropriate environmental mitigation measures.

A similar approach can also be applied to degraded areas which, if properly rehabilitated and reintegrated, could represent potential assets within the multifunctional green and blue infrastructure project.

Analysis of the map shows that the most extensive threats in terms of surface area are related to facilities and transformation areas outside the consolidated urban fabric in the valley floor, while in the mountain areas the primary threats are related to ski infrastructure. However, there are many critical issues at a smaller scale which, as mentioned above, are less visible at this scale but still have a significant impact on the fragmentation of ecological corridors and the associated loss of habitat. In particular, mobility infrastructure, existing facilities and degraded areas contribute to these ecological disturbances.

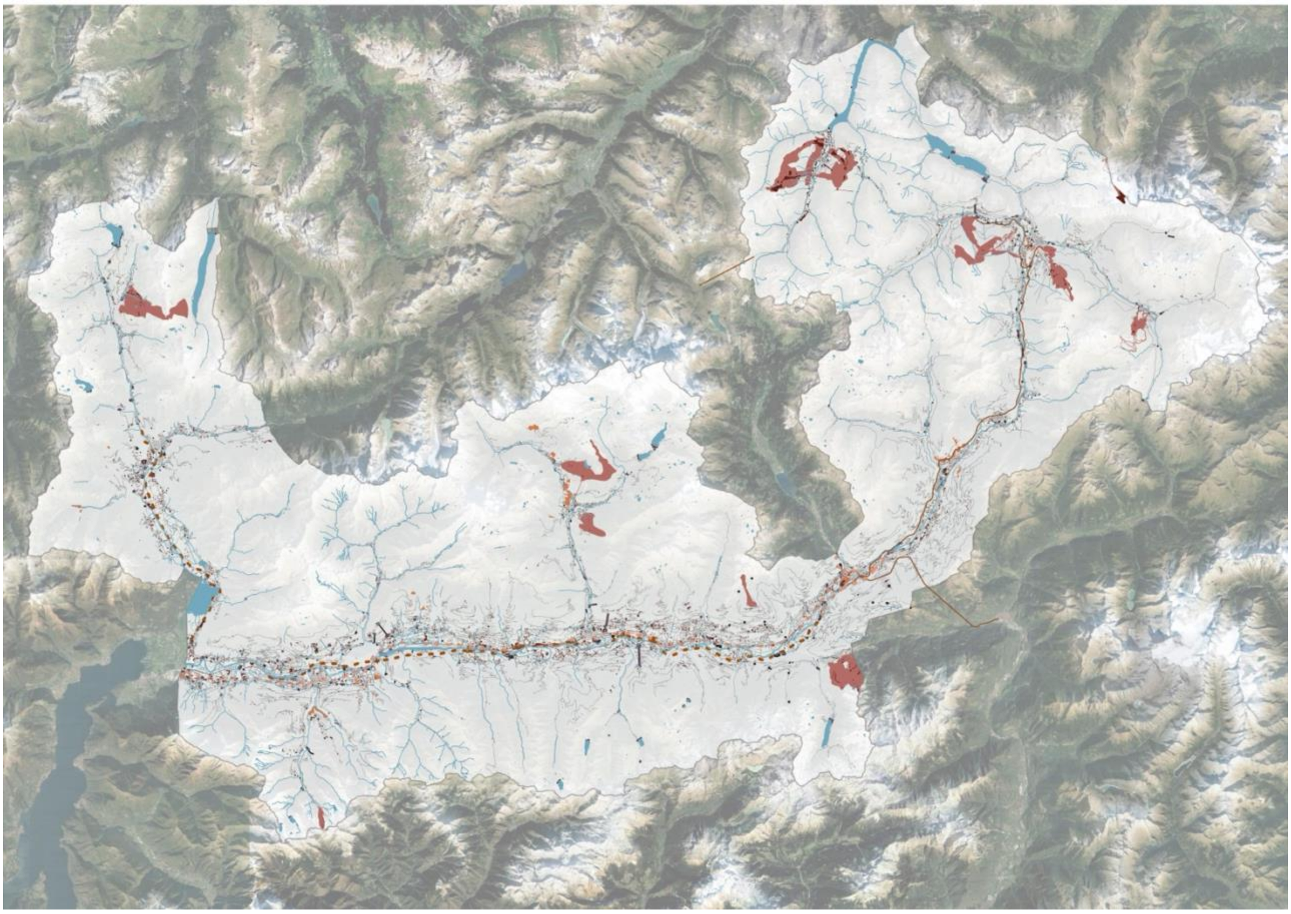

Figure 2 - Overview - Mapping of existing and expected major threats in the Province of Sondrio

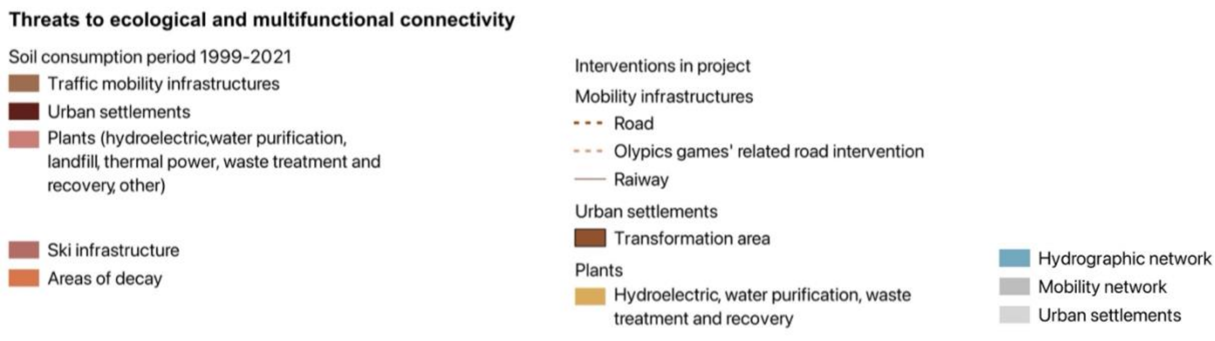

Table 5 - Existing and planned threats

Threat	Existing	Interventions in project
Mobility infrastructure	*Urbanized areas '99-2021* • 174 ha	• Rail → 86,4 ha • Infrastructure → 75 ha - *Cortina 2026 Olympics game → 18 ha*
Urban settlements	*Urbanized areas '99-2021* • 2460 ha	Transformation areas • 426 ha
Plants	*Urbanized areas '99-2021* • Phovoltaic plants → 2,7 ha • Public and private facilities → 7 ha • Technological plants → 56 ha **Total** 66 ha	• Hydroelectric → 0,6 ha • Thermal power plant → 3 ha • Waste treatment and recovery → 1,6 ha • Water treatment → 2,5 ha • Other (water regulation works, technological and mobility services)→ 6 ha **Total** 13,7 ha
Ski infrastructure	• 4900 ha	No comprehensive data available
Areas of decay	• 2,3 ha	/
TOTAL	~7600 ha	~600 ha

The following table lists the average dimension for each threatening category, helping to suggest suitable and realistic compensation measures foreseeing their implementation where the suitability criteria is respected.

Table 6 - Average transformation dimension

Threat	Average dimension (ha)
Mobility infrastructure	• Large scale *Rail* – 12,3 *Infrastructure* – 10,7 • Medium scale *Cortina 2026 Olympics game* – 6
Urban settlements (Transformation areas)	• Small scale – 0,7

Threat	Average dimension (ha)
Plants	• Small scale – 0,2

The analysis presented in the Figure 2 and Table 5 aims to highlight the extent of existing and planned critical issues within the province of Sondrio. Existing threats have been analyzed for the period 1999–2021, considering land consumption over this timeframe, particularly in relation to infrastructures, settlements, industrial facilities, ski infrastructures, and degraded areas. Each existing critical issue is associated with the corresponding planned development based on 2023 data.

Particular attention must be given to planned mobility infrastructures, as these represent strong linear barriers that further contribute to ecological fragmentation. Additionally, transformation areas—both in terms of urban settlements and service and industrial facilities—constitute a significant portion of new urbanization, which is likely to drive the expansion of urban centers and the consumption of additional natural land.
These planned projects underscore the pervasive need for renewable energy across the territory. This need is anticipated to escalate in the coming years due to recent European policies and the targets set for green energy production.
Finally, regarding ski infrastructures, comprehensive data covering the entire province is not available. However, given the region's vocation for winter tourism and the upcoming Olympic Games, it is certain that some infrastructures will be expanded to accommodate the increasing demand.

The following sections will analyse the issue of areas deemed unsuitable for the development of these projects, as well as the compensatory methodology that developers of such projects will need to consider.

5 Choice of Locations for major developments / renewable energy facilities

5.1 General criteria for unsuitable locations

The definition of unsuitable areas for the siting of renewable energy plants and other threats related to the fragmentation of ecological corridors was based on document D.1.3.1 and on the current national legislation, with additional considerations specific to the pilot case of the Province of Sondrio, as outlined in the following section.

Key excerpts from Legislative Decree 19/2024, the Consolidated Act on Renewable Energy Sources (TU FER), and the previous National Decree 199/2021, which regulate the administrative frameworks for renewable energy production, are provided. These regulations aim to simplify and unify authorization procedures within the sector.

The Consolidated Act on Renewable Energy Sources (TU FER) introduces a classification of territorial areas into four primary categories, each with specific characteristics and regulations regarding the installation of renewable energy facilities:

- Areas Suitable for RE Installations**:** These areas are designated for the installation of renewable energy plants. Their identification is based on criteria established at both national and regional levels, aiming to maximize available land for such facilities while ensuring the protection of landscapes, cultural heritage, agricultural resources, and the environment.
- Areas Not Suitable for RE Installations**:** These areas explicitly prohibit the installation of renewable energy plants. This classification serves to protect regions of significant environmental, landscape, or cultural value, where the presence of such facilities would cause substantial harm.
- Ordinary Areas: In these zones, the authorization procedures outlined in Legislative Decree No. 28/2011 apply. Renewable energy plants are allowed, but their installation is subject to specific authorization procedures, which vary depending on the type and size of the facility.
- Areas Where the Installation of Ground-Mounted Photovoltaic Systems is Prohibited: These areas are specifically designated to prevent the installation of ground-mounted photovoltaic systems, in order to preserve territorial features such as high-value agricultural lands or zones under landscape protection.

This classification aims to balance the need to promote renewable energy development with the necessity of safeguarding Italy's environmental, cultural, and landscape heritage.

The directive remains quite general, and at present, the Lombardy region has not yet adapted the national standard to the regional context. In the process of identifying suitable and unsuitable areas, regions must consider the maximization of available land, the protection of cultural heritage and landscapes, agricultural and forest areas, air quality, and water bodies. Priority should be given to utilizing built-up areas and those designated for industrial, craft, service, and logistics purposes, while also evaluating the suitability of areas that cannot be repurposed for other uses. Regions must also consider the potential for classifying areas as suitable based on the energy source, size, and type of facility, as well as the possibility of preserving temporarily designated suitable areas as outlined in Legislative Decree 199/2021.

This was related to the Italian normative framework, while widening the perspective to the alpine space framework in the table below are summarized the general criteria for unsuitable sites referring to the report D1.3.1 by Ifuplan.

Table 7 - General criteria for unsuitable sites (D1.3.1)

	Unsuitable locations
Hydropower	• protected areas (e.g. Natura 2000 areas, nature reserves, …) • natural or semi-natural rivers
Windpower	Neither existing or in project windpower plants in the pilot area
Solar power	• protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) • areas of high nature conservation value • riparian buffer zones, floodplains • natural watercourses and lakes • soil with very high significance for natural soil functions • agricultural soil with high degree of productivity
Biomass (bioenergy plant)	• protected areas (e.g. Nature 2000 areas, nature reserves, core areas of biosphere reserves, water protection areas) • areas of high nature conservation value

	Unsuitable locations
High voltage transmission line	• European bird protection areas (Important Bird Areas (IBAs) or Special Protection Areas (SPAs)) • wetlands of international importance according to the Ramsar Convention • designated bird migration routes • near large bodies of water and reservoirs • protected areas specifically for landscape (UNESCO World Heritage Sites, Landscape conservation areas, priority areas for tourism) • other protected areas (e.g. Natura 2000 areas, nature reserves, core areas of national parks and biosphere reserves) • old natural or semi-natural forests • water protection areas of zones I and II (no construction of transmission poles in waterways or banks of waterways
Roads/ highways	• protected areas (e.g. Nature 2000 areas, nature reserves, core zones of national parks and biosphere reserves, water protection areas) • areas of high nature conservation value like old-growth forests or wet- and peatland • soil with very high significancein terms of biodiversity
Railways	• protected areas (e.g. Nature 2000 areas, nature reserves, core zones of national parks and biosphere reserves, water protection areas) • areas of high nature conservation value like old-growth forests or wet- and peatland
Urban /industrial development	• protected areas (e.g. Nature 2000 areas, nature reserves, core zones of national parks and biosphere reserves, water protection areas) • areas of high nature conservation value like old-growth forests or wet- and peatland • existing ecological corridors, especially in bottleneck areas

5.2 Development of specific criteria for unsuitable locations in the pilot region (exclusion zones)

Exclusion zones in this context are areas where certain infrastructures are not allowed to be built or operated. Exclusion zones are the most common planning instrument to mitigate environmental impacts of human land-use, including the deployment of RE.
As can be seen from the table above, the unsuitable locations are often identical. They include mainly protected areas of various types: e.g. Nature 2000 areas, nature reserves, core zones of national parks and biosphere reserves, water protection areas or the

developed GBI network for connectivity (including priority areas for conservation and restoration). For the definition of exclusion zones, however, it is not sufficient to use only the boundaries of ecologically valuable areas. Many infrastructure projects have far-reaching effects (for example wind turbines or roads), so positioning them directly next to an ecologically valuable area can affect the area in a negative way. As described in report D1.3.1 edge effects and barrier or fragmentation effects influence not only the habitats adjacent to an infrastructure, but also the ecosystems and living conditions of wildlife in wider areas (see report D1.3.1).

The mentioned PlanToConnect project contribution report (report D1.3.1) considered the buffer method as a potential solution to ensure the protection of ecologically valuable areas in the event of threatening interventions.

The project for the Province of Sondrio follows a different approach that aligns with the strategic framework defined by the overarching initiative. Despite the variation in implementation methods, the ultimate objective remains unchanged: minimizing further fragmentation and degradation of the ecological and ecosystem components within the project area.

The constraints established for our project area align with current regulations; in some cases, they impose stricter limitations in areas of high natural and ecosystemic value or in strategic zones that redefine essential corridors for defragmentation within the green network design.

Two approaches were followed to define unsuitability rules and criteria:

1. The definition set by the national decree regulating the “suitable areas” for renewable energy plants implementation (Legislative Decree 19/2024 and in Legislative Decree 199/2021)
2. The interpretation of the strategic framework and objectives guiding the Multifunctional GBI for the province of Sondrio

The current regulations regarding suitable areas remain quite general, as they have not yet been adopted at the provincial level. As previously mentioned, these regulations establish basic guidelines for defining areas suitable for the implementation of renewable energy plants, primarily considering the environmental, cultural, and landscape value of the areas in question. They encourage the use of already urbanized areas, thus avoiding the occupation of land designated for other purposes. The decree emphasizes the importance of assessing the suitability of areas based on the scale of the proposed project. Given the limited constraints currently established at the national level, it seemed useful to further define the location of unsuitable areas following the structure of the GBI project.

In general, the constraints imposed align with the strategic frameworks outlined—namely, conservative, multifunctional, and regenerative—though certain exceptions exist for corridors and restoration areas that require additional protection.
The areas classified under the conservative framework, which include protected areas and SACA1 zones, correspond to regions with the highest levels of naturalness and ecological significance. It is essential that transformative interventions in these areas are avoided, particularly those that could pose potential threats to environmental quality.
The multifunctional strategic framework includes areas with high ecosystem service capacity and those contributing to multifunctionality, such as recreational infrastructures and land uses. This is where the core structure of the GBI project is concentrated. Regulatory constraints in these areas are less stringent, given their lower landscape and ecological value. While transformation restrictions will apply, they will be less severe than those in the conservative framework and will be adequately compensated, as detailed in the following section.
The regenerative framework consists of areas that have undergone significant urbanization but still contain zones of high ecological value within the provincial ecological network, as well as other green elements. This category also includes potential ecological corridors identified by the ecological network and the SACA framework, designated as suitable areas for defragmentation. These sub-categories will find a specific role in the next chapter and will be subject to strict constraints, while the remaining territory will allow for greater flexibility, always accompanied by appropriate compensatory measures and incentives for using already impermeabilized areas for any transformations.
Emphasizing the importance of the size of the plant and its relative impact on ecological and functional connectivity, the unsuitable areas and the corresponding compensatory measures consider the analysis previously presented on the average scale of transformations for each type of threat located within our project area.

5.3 Mapping the unsuitable areas

As previously mentioned, due to the absence of updated data on forecasts for renewable energy installations and other potentially threatening transformations, this chapter will feature a single map highlighting the different 'unsuitability' areas within the pilot case study. These areas are designated for conservation (protected and natural areas), enhancement (areas for multifunctional connectivity enhancement and restoration), or regeneration (areas for urban and environmental regeneration) and are therefore in conflict with potential future transformations.

The identification of four levels of unsuitability, which extend across the entire municipal territory, is of crucial importance. This is because any new land consumption poses a threat to the overall multisystemic value and to the ecological connectivity. The four distinct levels are defined as follows: two levels of unsuitability and two levels of criticality. The following sections provide further explanation.

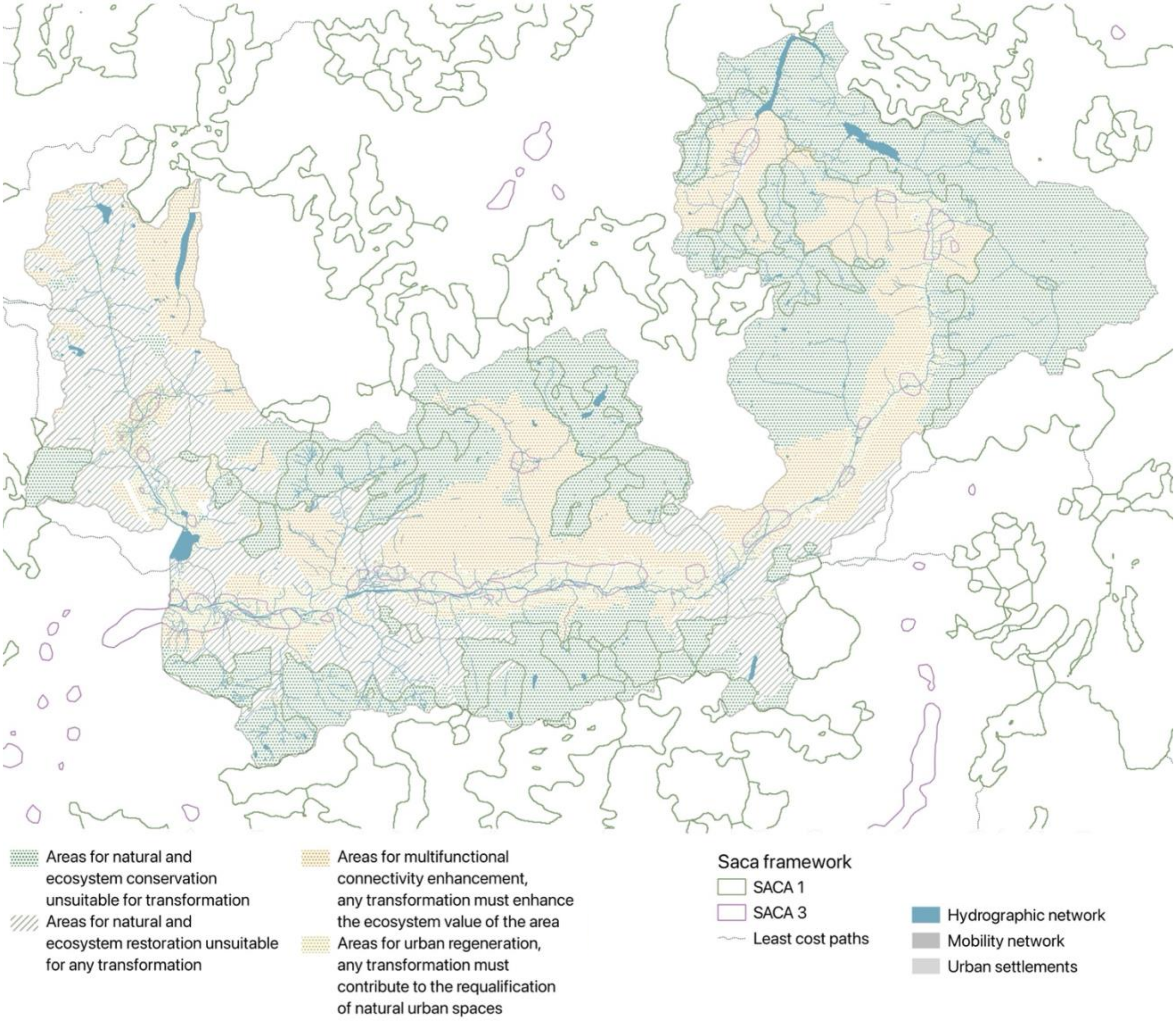

Figure 3 - Unsuitable and critical area for transformation

The first level concerns the *areas for natural and ecosystem conservation* unsuitable for transformation located within the Conservative framework. These areas, as previously outlined, constitute the natural heritage of the Alpine region, defined by the system of protected areas and SACA1 zones. No transformations should be permitted in these areas, in accordance with the conservative character of the multifunctional infrastructure of the project.

The second level, subject to the same restrictions in the design project, includes the areas designated as *restoration areas*, which will serve as defragmentation devices for the

urbanized valley corridor, essential for the ecological restoration of the project area. In these areas, the prohibition of transformation is not intended for conservation per se but rather for restoration, preventing further land consumption or the introduction of functions that are inconsistent with the renaturalization of the area.
Conversely, multifunctional areas (in legend *Areas for multifunctional connectivity enhancement, any transformation must enhance the ecosystem value of the area*), which exhibit high multi-systemic capacities and play a key role in shaping the multifunctional GBI project, follow a different regime. Given the necessity of minimizing land consumption—particularly in mountainous regions—and avoiding functions incompatible with the surrounding natural environment, any transformation deemed essential will require appropriate compensatory measures. These measures should be commensurate with the function and scale of the intervention as outlined in the next chapter. As with the multifunctional framework, the regenerative framework (in legend *Areas for urban regeneration, any transformation must contribute to the requalification of natural urban spaces*) will also include a provision for restrictions. If the planned interventions are deemed necessary and cannot be located in already urbanized, abandoned, and/or degraded areas, they must be adequately mitigated and compensated. This approach is intended to ensure alignment with the objectives of the GBI project for these areas, namely urban regeneration and the defragmentation of the dense and compact urban corridor.

A detailed analysis of the planned transformations as of the 2023 project status was therefore conducted, with the goal of assessing which of these should be proposed for modification with the implementation of the Green and Blue Infrastructure (GBI) project as a contribution for the update of local spatial planning instruments. Indeed, the analysis revealed that the environmental value of the sites and the related impacts of the transformations had not been adequately considered in the drafting of the provincial plan and the subordinate local plans.
Our study examines the overlap between the proposed conversions and the unsuitable areas identified in the project.
For the first category concerning the unsuitable areas for natural and ecosystem conservation, approximately 35 ha of new transformations are planned, mainly for tertiary, tourism/hospitality and infrastructure developments.

The second, the restoration areas framework, which follows the same restrictive regime as the Conservation Framework, foresees about 70 ha of transformations. These include mainly residential, industrial, waste treatment and recycling facilities and infrastructure developments.

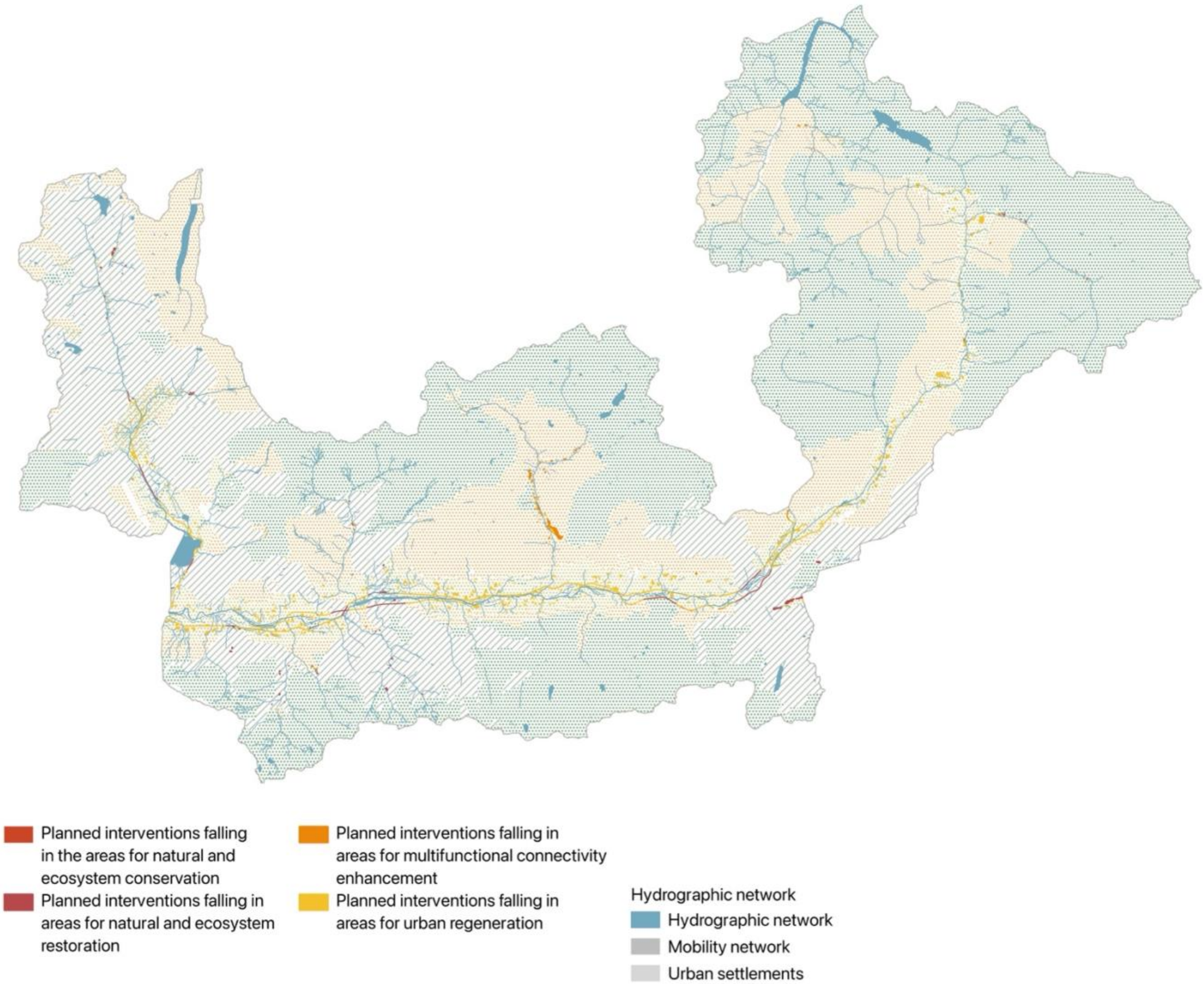

Figure 4 - Foreseen interventions in the pilot project

Threat	Transformation area	Plants	Infrastructure	Total
Conservative framework *Areas for natural and ecosystem conservation*	• 26 ha	• 0,7 ha	• 8 ha	→ ~35 ha
Restoration framework *Areas for natural and ecosystem restoration*	• 48 ha	• 0,8 ha	• 21 ha	→ ~70 ha

Threat	Transformation area	Plants	Infrastructure	Total
Multifunctional framework *Areas for multifunctional connectivity enhancement*	• 84 ha	• 0,3 ha	• 4 ha	→ ~88 ha
Regeneration framework *Areas for urban regeneration*	• 337 ha	• 12 ha	• 150 ha	→ ~500 ha

Under the multifunctional framework, about 88 ha of land is expected to be developed. The main planned developments are tourism, hospitality, tertiary functions and infrastructure development.

Finally, within the regenerative framework, the planned transformations increase significantly. As this framework is located in the urban core, the availability of accessible vacant land increases, as does its attractiveness and demand. Around 500 hectares of interventions are planned here, mainly for services, housing and industrial functions.

The results of this analysis highlight the significant number of planned transformations in areas highly vulnerable to anthropogenic presence, which, if our project were applied, would be classified as unsuitable. Equal attention must be given to critical areas, where substantial efforts should be made to relocate planned land-use transformations from undeveloped land to already urbanized but currently unused areas. This approach could effectively prevent further land consumption and mitigate environmental impacts.

The identification of unsuitable and critical areas, carried out in parallel with the design of the green infrastructure project, will have regulatory implications within the multifunctional green and blue infrastructure (GBI) framework, as it will be integrated in the document D.2.5.1. These new regulations will influence planning design and will contribute significantly to the protection and maintenance of ecological connectivity, while allowing for defragmentation and reconversion in densely anthropised valley bottoms.

6 Possible mitigation and compensation measures

The proposed compensation mechanism for the Province of Sondrio was inspired by the acknowledged Bavarian "Ökokonto" and "Flächenpool" model, which since the early 2000s has proven effective in restoring the same environmental value lost due to urbanisation. Most importantly, by ensuring that no new urban development takes place once the availability of greenfield sites for compensation is exhausted.

A brief summary of this approach is provided below.

The Ökokonto method, included within the document 'Guide to the Regulation of Interventions in Urban Land Use Planning' by the Federal State of Bavaria (2021)[2], ensures that all land-use changes linked to urbanization are assessed and compensated to minimize environmental impact. Each municipality designates a reserve of land for ecological restoration, from which developers must acquire mitigation credits to offset damages. If the Green Deposit is depleted, no building permits can be issued. Compensation is quantified through the Ecological Account (Ökokonto), considering ecological relevance, land sealing (Versiegelungsgrad), and mitigation efforts, using a compensation factor (Faktor der Kompensation – FDC). Restoration measures must be implemented before development begins.

Our approach customizes and expands upon this model by incorporating, where possible, a direct and tangible solution to land degradation: the active de-sealing of previously urbanized soils. While the establishment of a Green Deposit and the quantification of an Ecological Account remain essential, the emphasis on soil de-sealing as a compensatory action ensures a concrete and measurable contribution to restoring ecological connectivity and ecosystem functions. This methodological enhancement strengthens the effectiveness of compensation strategies, aligning them more closely with the ecological and territorial specificities of the Alpine region.

By following the framework of soil and biodiversity regulations, our project aims to emphasize the desealing technique in alignment with the "no net land take" approach. This strategy together with the recently adopted EU Soil Monitoring Law explicitly aims to protect

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[2] Bayerisches Staatsministerium für Wohnen, Bau und Verkehr. Bauen im Einklang mit Natur und Landschaft: Eingriffsregelung in der Bauleitplanung. Ein Leitfaden. Bayerisches Staatsministerium für Wohnen, Bau und Verkehr, 2021. Available on Bestellen Bayern website.

and restore soil health and promoting the goal of achieving no net land take by 2050, highlighting the urgent need to reverse soil degradation. It encourages Member States to implement measures that minimize land consumption and actively promote desealing and it establishes a mandatory soil health monitoring system will be implemented using a harmonized EU-wide methodology to inform policy decisions and land management strategies.

The fundamental principle of this approaches is to counterbalance new land consumption by restoring previously sealed or artificialized areas. The primary objectives include the protection of valuable soils, the preservation of biodiversity, and the reduction of impervious surfaces. Over time, in the long term, desealed areas can gradually undergo natural regeneration, restoring essential soil functions such as water retention, vegetation growth, and the enhancement of ecological and ecosystem services.
The "no net land take" approach emphasizes a hierarchy of mitigation:

- Avoidance: Prevent land take whenever possible;
- Minimization: Reduce the extent of land take;
- Compensation: Offset unavoidable land take through measures like desealing;
- Quantification: Developing methods to accurately quantify land take and compensation is essential for effective implementation;
- Context-Specific Measures: The most appropriate compensation measures will vary depending on the local context;

In essence, desealing is a fundamental component of "no net land take" strategies, providing a direct and effective way to compensate for the impacts of land consumption.

In certain instances, the de-sealing technique may not be a viable option due to structural and morphological characteristics. Consequently, it will be necessary to delineate the Green Deposit. The definition and identification of Green Deposit areas must be integrated into the Green and Blue Infrastructure (GBI) planning process, making them strategic nodes for supra-local ecological connectivity. These areas are typically public; however, in their absence, agencies may acquire private land through purchase or agreements for ecological restoration with landowners. The availability of these areas is a prerequisite for project approval, establishing a strong link between the agency and municipal/provincial administrations.

For the quantification of the Ecological Account in our specific case study, three key aspects are considered, slightly diverging from the German model:

1. Ecosystemic relevance of the area to be transformed, is defined by its multisystemic value, which serves as the knowledge base for the GBI design. Three levels of relevance—low, medium, or high—will represent the value lost due to transformation.
2. Sealing ratio, to assess the level of soil impermeabilization caused by the transformation.
3. Function of the transformation, determined by its potential environmental and ecological impact.

The combination of these three parameters defines the compensation factor. The compensation factor will be useful, in the case of possible de-sealing, in sizing the area to be de-sealed in proportion to the area of intervention and the ecosystem value of the soils concerned. If de-sealing is impossible, it will be useful in calculating the compensation area. In this case, compensation measures will be tailored to the specific characteristics of the intervention area and the needs of the multifunctional network.

As mentioned, the soil de-sealing tecnique will be highly supported when feasible, as well as other solutions related to the intensification of climatic events, especially in alpine areas, must be implemented. Other interventions may include water retention systems designed to manage not only extreme rainfall events but also the progressive melting of glaciers. Additionally, measures will address biodiversity loss, the proliferation of invasive species, and rising temperatures.

A list of all possible mitigation and compensation measures can be found in the Annex 2., based on the corresponding chapters of the report D1.3.1.

7 Conclusions

The increasing expansion of renewable energy infrastructure presents significant challenges to ecological connectivity and environmental integrity, particularly in sensitive alpine regions. While the transition to renewable energy is a critical priority, it must be carefully managed to prevent fragmentation of the Green and Blue Infrastructure (GBI) network and degradation of ecosystem functions. This report highlights how planned land-use transformations, including renewable energy developments, may pose threats to ecological connectivity by disrupting habitat continuity and altering key ecological processes.

Through a spatial analysis of the province of Sondrio, the study identifies unsuitable areas where new developments should be restricted and critical areas where interventions may be permitted under specific compensatory measures. The proposed compensation strategy follows the "no net land take" approach aimed at mitigating environmental impacts through de-sealing and ecosystem restoration. Inspired by models such as Ekoconto and Flächenpool, this methodology promotes the avoidance of excessive soil consumption and through the green deposit enhances habitat connectivity, ensuring that territorial transformations align with ecological sustainability principles.

The integration of ecological criteria into spatial planning and regulatory frameworks is essential to safeguarding biodiversity while accommodating necessary energy transitions. Additionally, the availability of high-resolution geospatial data remains a fundamental requirement for the effective implementation of evidence-based planning strategies. A comprehensive and adaptive approach to spatial planning, informed by georeferenced data, will be crucial in balancing renewable energy expansion with the preservation of ecological connectivity in the Alpine region.

8 Glossary

Connectivity" (structural and functional)	**"Connectivity comprises two components, structural and functional connectivity. It expresses how landscapes are configurated, allowing species to move. Structural connectivity, equal to habitat continuity, is measured by analysing landscape structure, independent of any attributes of organisms. […]. Functional connectivity is the response of the organism to the landscape elements other than its habitats (i.e. the non-habitat matrix). This definition is often used in the context of landscape ecology. A high degree of connectivity is generally linked to low fragmentation." (EUROPEAN COMMISSION - Technical information on Green Infrastructure (GI), 6.5.2013, Glossary)** **(Definition of connectivity see also Deliverable 1.1.1, chapter 8)**
GBI – Green and blue infrastructure	Green infrastructure (GI) is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings." (EUROPEAN COMMISSION - Green Infrastructure (GI) — Enhancing Europe's Natural Capital, 6.5.2013) (Definition of connectivity see also Deliverable 1.1.1, chapter 6)
Hydropower (dams, weirs, run-off-river power plant)	power derived from the energy of falling water or fast running water to generate electricity Hydropower generation including development and use of associated infrastructure (e.g. building dams or weirs, changes of hydrological functioning rivers or chemical and thermal properties of water due to operation of dams and weirs).
Hydroelectric dam	a barrier that stops or restricts the flow of water; used to create energy in the water flow that can be captured by a turbine to generate electricity
Pressures and Threats	Definition by the European Environment Agency 2020 (State of nature in the EU - Results from reporting under the nature directives 2013-2018): *"Pressures are considered to be factors that have affected habitats and species within the current reporting period, while threats are factors that are anticipated to be likely to have an impact during the subsequent two reporting periods."*
Solar PV panel	an arrangement of PV materials that absorbs and converts sunlight into electricity

Transmission lines	power lines used to move electricity from a generating site (e.g., a power plant) to an electrical substation, which often transforms the voltage from high to low before reaching consumers

9 References

Bayerisches Staatsministerium für Wohnen, Bau und Verkehr. Bayerisches Staatsministerium für Wohnen, Bau und Verkehr, (2021).
https://www.bestellen.bayern.de/application/applstarter?APPL=eshop&DIR=eshop&ACTIONxSETVAL(artdtl.htm,APGxNODENR:352254,AARTxNR:03500286,AARTxNODENR:365000,USERxBODYURL:artdtl.htm,KATALOG:StMB,AKATxNAME:StMB,ALLE:x)=X

Convenzione delle Alpi. Convenzione quadro. (1991)
https://www.alpconv.org/fileadmin/user_upload/Convention/IT/Framework_Convention_IT.pdf

Convenzione delle Alpi. Dichiarazione sulla Protezione della biodiversità montana e la sua promozione a livello internazionale. (2020)
https://www.alpconv.org/fileadmin/user_upload/Organisation/AC/XVI/ACXVI_MountainBiodiversityDeclaration_it.pdf

Ciria. The SuDS Manual (2015)
https://www.unisdr.org/preventionweb/files/49357_ciriareportc753thesudsmanualv5.comp.pdf

European Commission. Knowledge for policy. Biodiversity. Actions Tracker. EU Biodiversity Strategy Actions Tracker.(2023).
https://dopa.jrc.ec.europa.eu/kcbd/actions-tracker/

European Commission. Biodiversity Strategy for 2030 (2023)
https://environment.ec.europa.eu

European Commision. EU Soil Monitoring Law (2024)
https://www.consilium.europa.eu/en/press/press-releases/2024/06/17/soil-monitoring-law-eu-on-the-pathway-to-healthy-soils-by-2050/

European Environment Agency. Conservation status of habitat types and species: datasets from Article 17, Habitats Directive 92/43/EEC reporting (aggiornato al 13/11/2023)
https://www.eea.europa.eu

European Environment Agency. Nature-Based Solutions in Europe: Policy, Knowledge and Practice for Climate Change Adaptation and Disaster Risk Reduction, EEA Report No 1/2021)
https://www.eea.europa.eu

Millenium Ecosystem Assessment. Ecosystem and human well-being (2005)
https://www.millenniumassessment.org

Decreto Aree Idonee. Ministero dell’ambiente e della sicurezza energetica (2024)
https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2024-07-02&atto.codiceRedazionale=24A03360&elenco30giorni=true

Disciplina per l'individuazione di superfici e aree idonee per l'installazione di impianti a fonti rinnovabili. Ministero dell’ambiente e della sicurezza energetica (2024)
https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2024-002&atto.codiceRedazionale=24A03360&elenco30giorni=true

Regione Lombardia. Osservatorio Regionale della Biodiversità (aggiornato al 15/12/2016)
https://www.regione.lombardia.it
Regione Lombardia. Rete Ecologica Regionale (aggiornato al 15/12/2016)
https://www.regione.lombardia.it
Regione Lombardia. Piano Territoriale Regionale (2010)
https://www.regione.lombardia.it
Regione Lombardia. Strategia Regionale per la Biodiversità. Linee prioritarie (2022)
https://www.svilupposostenibile.regione.lombardia.it
Provincia di Sondrio. Piano Territoriale di Coordinamento Provinciale (2009)
https://www.provinciasondrio.it
SOS4Life - Norme, linee guida, buone pratiche, casi studio in norma di limitazione di consumo di suolo e resilienza urbana al cambiamento climatico (2017)
https://www.sos4life.it
Istituto superiore per la protezione e la ricerca ambientale – ISPRA (2012). Reti ecologiche e Pianificazione del Territorio e del Paesaggio
https://www.isprambiente.gov.it
Istituto superiore per la protezione e la ricerca ambientale – ISPRA (2016). Consumo di suolo, dinamiche territoriali e servizi ecosistemi
https://www.isprambiente.gov.it

Andrea, A., Silvia, R., & Stefano, S. (2016). Managing Multiple Ecosystem Services for Landscape Conservation: A Green Infrastructure in Lombardy Region. *World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium WMCAUS 2016*, 2297–2303.
Salata, S., Garnero, G., Barbieri, C., & Giaimo, C. (2017). The Integration of Ecosystem Services in Planning: An Evaluation of the Nutrient Retention Model Using InVEST Software. *Land*, *6*(3), 1–21. https://doi.org/10.3390/land6030048
Stefano, S., Silvia, R., Andrea, A., & Federico, G. (2017). Mapping Habitat Quality in the Lombardy Region, Italy. ONE ECOSYSTEM, 2, 1–8. https://doi.org/10.3897/oneeco.2.e11402

Salata, S. (2023). Filling the Gaps in Biophysical Knowledge of Urban Ecosystems: Flooding Mitigation and Stormwater Retention. Land, 12(3). https://doi.org/10.3390/land12030702

ANNEXES

Annex 1 Mitigation /compensation (see D1.3.1)

	Mitigation / Compensation
Hydropower	• Upstream and downstream fish passage facilities (fish ladders, bypasses) to allow migration • intelligent turbine design or turbine shutdown on a fixed schedule decreasing turbine related mortality • ecologically effective minimum flow of water • bed-load management • morphological enhancement measures: ➢ improvement of the riverbank structure (unsealing the riverbank) ➢ introduction of gravel banks ➢ introduction of disturbance elements (stones, deadwood) • New hydropower technologies with less environmental impacts
Windpower	• turbine design optimization • switch off systems at times of increased bird/bat activity to prevent/avoid collisions (Automatic anti-collision systems) • unattractive design of the environment at the base of the mast and in surrounding fields for wind energy-sensitive birds (red kites)
Solar power	• landscape-oriented design of the facility, visual integration into the environment: suitable arrangement of the solar panels (e.g. “Solar biotope network”) • sufficiently large (wide) open spaces between the rows of solar panels (sunlit strips at least 3 m wide between the rows) • elevation of the solar panels (panel distance to the ground at least 0.8 m) • no fencing or at least permeable for small and medium-sized mammals (15 cm distance between the fence and the ground), migration corridors as crossing aids for large-scale facilities • development and maintenance of extensively used, species- and flower-rich grassland in the solar park ➢ using seeds from local species or locally obtained mown material ➢ no fertilization, no use of pesticides ➢ up to 2 mowing intervals (use of insect-friendly mower, cutting height 10 cm) with removal of mowed material or/and site-adapted grazing • no mulching
Biomass (bioenergy plant)	• -

	Mitigation / Compensation
High voltage transmission line	• bundling of linear infrastructure, appropriate route alignment • appropriate design of the pylons to reduce fragmentation including spanning above the forest canopy • marking transmission lines to reduce bird collision risk • ecological rights-of-way vegetation management creating and connecting new habitats
Roads/ highways	• appropriate route alignment • traffic management measures: reducing traffic volume or speed • fencing combined with wildlife passages • wildlife passages as overpasses (e.g. green bridge, fauna overpass, multiuse overpass) or as underpasses (e.g. viaduct, fauna underpass, multiuse underpass, small fauna underpass, adapted culverts, fish passage, amphibian passage) reducing the barrier effect and providing a safe crossing • embankments to mitigate noise and provide new habitats for endangered flora species • adapting infrastructure verges • mechanical methods for vegetation control or grazing as alternative methods to the use of chemical substances in the management of green areas • adapting road lighting for mitigating light pollution • noise screens, placing the road between cuttings or earthen mounds, silent pavements for mitigating noise • runoff water management: Retention ponds
Railways	• appropriate route alignment • fencing combined with wildlife passages • wildlife passages as overpasses (e.g. green bridge, fauna overpass, multiuse overpass) or as underpasses (e.g. viaduct, fauna underpass, multiuse underpass, small fauna underpass, adapted culverts, fish passage, amphibian passage) reducing the barrier effect and providing a safe crossing • embankments/ earthworks to mitigate noise and provide new habitats for endangered species • adapting infrastructure verges • mechanical methods for vegetation control or grazing as alternative methods to the use of chemical substances in the management of green areas • noise screens, placing the road between cuttings or earthen mounds, rail noise absorbers for mitigating noise • runoff water management: Retention ponds

	Mitigation / Compensation
Urban /industrial development	• appropriate location of new urban/industrial development (avoid areas of high nature conservation value including ecological corridors) • preservation of large, undissected open spaces, safeguarding inner-urban trees (particularly large/mature trees) • minimizing the road infrastructure associated with urban/industrial development, keeping vehicle speeds low • reducing use of fertilizers and pesticides in maintenance of public and private green • minimizing artificial lighting • good pet ownership to reduce domestic animal damages to wildlife • runoff water management: minimize water runoff into streams • Integration of connectivity elements in zoning plans / optimising connectivity planning and interfaces between regional concepts and municipal planning

PlanToConnect

Mainstreaming ecological connectivity in spatial planning systems of the Alpine Space

Project partners:

Urban Planning Institute of the Republic of Slovenia (SI)
Veneto Region (IT)
ALPARC – the Network of Alpine Protected Areas (FR)
Asters, organisation for the conservation of natural areas in Upper Savoy (FR)
Eurac Research (IT)
ifuplan - Institute for Environmental Planning and Spatial Development (DE)
University of Würzburg (DE)
Salzburg Institute for Regional Planning and Housing (AT)
E.C.O. Institute of Ecology Ltd. (AT)
Fondazione Politecnico di Milano (IT)

D.2.4.1 GBI-network: Land use conflicts for RE production and other threats

Author(s)

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In collaboration with:

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Layout

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