Evaluating Biodiversity Enhancement in Wind Energy - The Pretul Wind Park Case Study

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This paper assesses the biodiversity enhancement performance of the Pretul Wind Park, Styria, Austria against the ten IUCN Good Practice Principles for biodiversity enhancement at wind and solar developments. Key enhancement measures include renaturalisation of the Schwarzriegelmoos raised bog, reforestation with over 1,500 native trees, targeted habitat improvements for black grouse and capercaillie, protective elevated footbridges and platforms to reduce trampling, and integrated scenic trails that guide tourism away from sensitive zones. The evaluation is based on analysis of EIA reports, baseline surveys (2013–2014), long-term monitoring data, official project documentation, and an interview with the operator (Österreichische Bundesforste). Seven of the ten principles are fully met, supported by early, evidence-based, additional, measurable, and timely actions that deliver verifiable net-positive outcomes. The remaining three principles, which concern stakeholder engagement, management, monitoring, reporting, and long-term sustainability, are only partly met due to regionally focused engagement, operator-led oversight, and absence of explicit perpetual or post-decommissioning mechanisms. The study demonstrates that alpine wind projects can exceed legal requirements and achieve meaningful biodiversity gains, but stronger inclusivity, comprehensive ecosystem monitoring, and secured long-term legacy instruments are essential for full IUCN alignment and genuine nature-positive impact.

1 Introduction

The rapid expansion of renewable energy sources is essential for mitigating climate change and achieving global decarbonization targets (Lee et al., 2023). Onshore wind energy, in particular, has emerged as a key contributor to this transition due to its scalability, cost-competitiveness, and substantial potential to reduce greenhouse gas emissions. However, the deployment of wind farms can pose significant risks to biodiversity, including habitat fragmentation, direct mortality from collisions (especially for birds and bats), behavioral displacement, disturbance during construction and operation, and alteration of sensitive ecosystems such as high-alpine moorlands and grasslands (Jobson et al., 2024; Marques et al., 2014; Katzner et al., 2025). These impacts are often amplified in ecologically sensitive regions like alpine areas, where species such as black grouse and capercaillie are already vulnerable due to habitat specificity and low population densities. While traditional environmental impact assessments (EIA) and mitigation hierarchies (avoid, minimize, restore, offset) address negative effects, they frequently fall short of delivering net positive outcomes for biodiversity (Jobson et al., 2024). A growing recognition exists that renewable energy projects should not only minimize harm but actively enhance biodiversity to contribute to broader nature-positive goals amid accelerating energy transitions and biodiversity loss. The International Union for Conservation of Nature (IUCN) has therefore developed ten Good Practice Principles for biodiversity enhancement at wind and solar developments, emphasizing proactive, evidence-based, additional, measurable, stakeholder-inclusive, and long-term measures beyond mandatory mitigation (Jobson et al., 2024). Despite this guidance, empirical case studies evaluating real-world application of these principles, particularly in high-altitude European contexts, remain limited, highlighting a research gap in assessing how onshore wind projects can achieve genuine biodiversity gains while supporting spatial development strategies in mountainous regions. This paper addresses this gap through a detailed case study of the Pretul

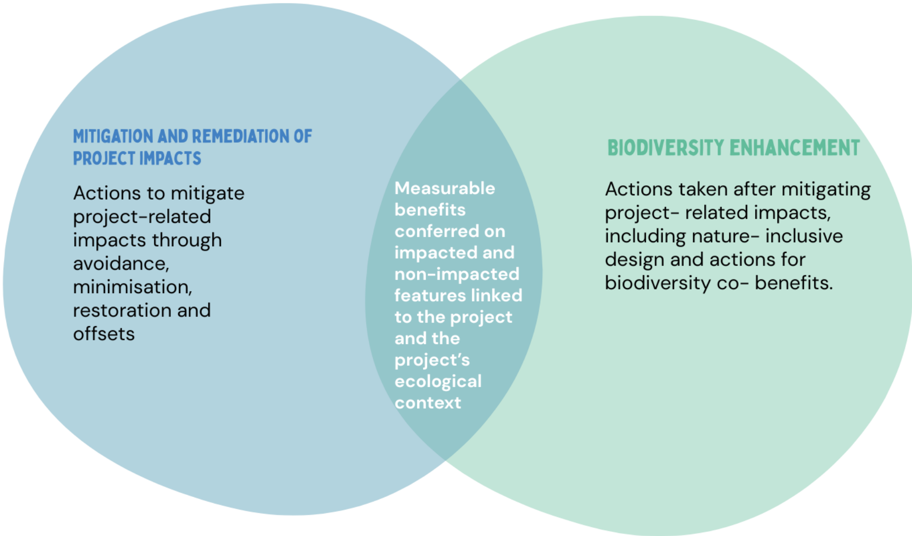

Figure 1: Mitigation vs. Enhancement (Jobson et al., 2024)

Wind Park in Styria, Austria. The main research question is: How well does the Pretul Wind Park perform against the 10 IUCN Good Practice Principles for biodiversity enhancement? Three sub-questions guide the analysis: (1) Which principles are met, partly met, or missing? (2) Are the implemented measures truly additional to legal mitigation requirements? (3) Which IUCN-recommended opportunities for onshore wind biodiversity enhancement remain unused? The objectives are to evaluate the project's biodiversity measures, identify strengths and weaknesses, and derive recommendations for improved alignment with best practices. The paper is structured as follows: Section 2 presents the literature review; Section 3 outlines the methodology; Section 4 provides a detailed description of the Pretul Wind Park and its context; Section 5 presents the principle-by-principle evaluation of biodiversity enhancement performance against the 10 IUCN Good Practice Principles; Section 6 discusses overall strengths, weaknesses, and unused opportunities identified in the analysis; and Section 7 offers conclusions along with implications for spatial development strategies in alpine renewable energy planning.

2 Literature Review

To establish a clear conceptual foundation for this study, it is essential to delineate the fundamental differences between mitigation and biodiversity enhancement, as articulated in the IUCN framework. The mitigation hierarchy (avoid, minimize, restore/rehabilitate, offset) represents the mandatory, regulatory standard for managing adverse biodiversity impacts from development projects, including onshore wind energy. Its purpose is to anticipate, prevent, reduce, or compensate for project-specific harm such that residual effects are neutralised or, at minimum, no net loss (NNL) is achieved. Mitigation actions are therefore compensatory and impact-specific: they directly address the biodiversity losses caused by the project itself, such as habitat clearance for turbine foundations or disturbance during construction (Jobson et al., 2024).Biodiversity enhancement, by contrast, comprises voluntary, additional conservation actions that measurably improve biodiversity beyond what is required under the mitigation hierarchy (see Fig. 1). Enhancement is not a substitute for mitigation but an extra layer of positive intervention, aimed at delivering genuine net-positive gains for biodiversity features that are linked to, associated with, or affected by the project, even if those features were not directly harmed. Key distinctions between mitigation and biodiversity enhancement are summarised in Table 1.

Aspect	Mitigation	Biodiversity Enhancement
Requirement	Mitigation is obligatory under environmental permitting (e.g., EIA processes)	Enhancement is discretionary and aspirational
Relation to impact	Mitigation counters project-induced losses	Enhancement creates additional benefits above baseline conditions
Outcome ambition	Mitigation targets no net loss (or net positive impact for directly affected features)	Enhancement targets verifiable net gain
Scope	Mitigation is limited to offsetting residual project impacts	Enhancement may target broader, project-linked biodiversity opportunities

Table 1: Mitigation vs. Enhancement (Jobson et al., 2024)

These differences are critical in the renewable energy sector, where the scale and pace of deployment demand approaches that not only avoid harm but actively contribute to reversing biodiversity decline. Building on this distinction, the International Union for Conservation of Nature (IUCN) has advanced a structured voluntary framework in its 2024 report "Opportunities for Enhancing Biodiversity at Wind and Solar Energy Developments". The report presents ten Good Practice Principles to guide the design, implementation, and evaluation of biodiversity enhancement measures (Jobson et al., 2024):

1. Target enhancement actions on biodiversity directly linked to, associated with, or affected by the project.
2. Consider enhancement opportunities early in the project cycle.
3. Ensure measures are evidence-based.
4. Establish a robust biodiversity baseline early in the project lifecycle.
5. Ensure enhancement measures are additional to mitigation actions.
6. Ensure enhancement actions are measurable with clearly defined goals and outcomes.
7. Identify and scope measures through collaborative stakeholder engagement.
8. Plan implementation within a timeframe relevant to the project.
9. Implement appropriate management, monitoring, and reporting requirements.
10. Plan for enhancement outcomes to be sustained in the long term, ideally in perpetuity.

These principles collectively promote a shift from compliance-driven harm reduction to ambitious, scientifically grounded, and enduring biodiversity contributions. Despite increasing policy momentum, evidenced by mandatory biodiversity net gain requirements in England and emerging provisions in the EU Nature Restoration Regulation, empirical evaluations of the IUCN principles in operational onshore wind developments remain scarce. The extant literature continues to emphasise impact identification and mitigation efficacy (Katzner et al., 2025; Marques et al., 2014), with species-specific research on black grouse and capercaillie primarily documenting displacement, collision risks, and habitat avoidance rather than voluntary enhancement results (Coppes et al., 2020; Taubmann et al., 2021). In high-altitude European contexts, where wind potential is substantial but ecological recovery protracted and tourism pressures acute, documented enhancement initiatives are largely confined to project-specific environmental reports rather than systematic, peer-reviewed scrutiny. This paucity of rigorous, principle-based case studies constitutes a significant research gap: the practical application and effectiveness of comprehensive voluntary enhancement frameworks in alpine onshore wind projects remain underexplored. The present study addresses this gap through a detailed evaluation of the Pretul Wind Park against the full suite of IUCN (2024) principles, thereby contributing empirical insights into the feasibility, outcomes, and potential for refinement of biodiversity enhancement in ecologically sensitive mountainous environments.

3 Methods

This study employs a qualitative, single-case study approach to evaluate the biodiversity enhancement performance of the Pretul Wind Park against the 10 IUCN Good Practice Principles for biodiversity enhancement at wind and solar energy developments. The case study method is particularly suitable for in-depth analysis of a real-world project in its specific alpine context, allowing detailed examination of implementation, outcomes, and alignment with international best-practice guidance (K

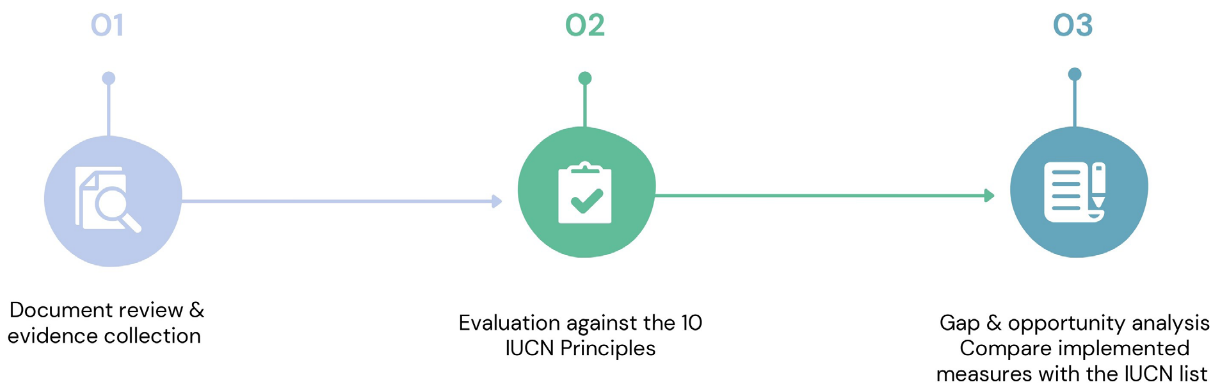

Figure 2: Methology

Figure 3: Project site - Source: Office of the Styrian Government

Robert, 2018). The methodological framework of this study follows a three-step process (see Fig. 2). Each principle was assessed using explicit evaluation criteria derived directly from the IUCN (2024) document, including the stated rationale, recommended actions, and key considerations. The assessment proceeded in three sequential steps: Evidence mapping: Relevant project information was extracted from official sources and mapped to each of the ten principles.

Performance assessment: Implementation for each principle was classified as:

- Met: clear, consistent, and well-documented full compliance;
- Partly met: partial fulfilment with evident gaps in scope, quantification, permanence, or outcomes;
- Not met: absent or insufficient evidence.

Gap and opportunity analysis: Implemented measures were benchmarked against the specific onshore wind biodiversity enhancement opportunities recommended by IUCN (2024), including habitat creation/restoration, targeted species support, landscape connectivity improvements, additional ecological features, and integrated long-term monitoring.

3.1 Data Collection

Data were collected through a comprehensive document review of publicly available primary and secondary sources. Key documents include:

- Environmental Impact Assessment (EIA) reports and summaries for the original Pretul Wind Park and its extension providing baseline data, impact descriptions, mitigation measures, and enhancement actions.
- Project documentation and press releases from the operator Österreichische Bundesforste AG (ÖBf).
- Interview with the project owner, Österreichische Bundesforste AG (ÖBf), providing additional insights into project planning, implementation, long-term management, and biodiversity enhancement measures.

- Media and association reports.
- The IUCN guidance document itself, serving as the analytical framework.

All sources were accessed via official websites, repositories, linked PDFs, and an interview with the project owner. No primary field data collection was conducted; the study relies on a combination of existing documentation and expert input to ensure objectivity and replicability.

3.2 Analytical Framework

The evaluation follows a structured approach based on the 10 IUCN Good Practice Principles. These principles are grouped thematically for clarity:

- Foundational Planning and Scoping (Principles 1, 3, 4)
- Timely Integration and Implementation (Principles 2, 8)
- Beyond Mitigation: Additionality and Measurability (Principles 5, 6)
- Engagement and Oversight (Principles 7, 9)
- Long-Term Legacy (Principle 10)

Limitations include reliance on secondary sources (potential reporting bias) and absence of independent verification of monitoring data. However, the use of multiple official documents mitigates these risks and provides a robust basis for the case evaluation.

3.3 The Pretul Wind Park (Styria, Austria)

The Pretul Wind Park (Windpark Pretul), situated in the high-alpine region of Pretul Mountain at approximately 1,600 meters above sea level in Styria, Austria, stands out as a compelling example of how renewable energy infrastructure can be developed in harmony with biodiversity enhancement and ecosystem management. Operated by the Austrian Federal Forests (ÖBf), this project integrates wind power generation with proactive environmental stewardship and community benefits, aligning closely with Austria's national goals for renewable energy expansion and nature conservation (see Fig. 3).

The wind park achieved full operational status for its current phases as of 2025, building on an initial phase launched in 2017 and a significant expansion completed in 2024. According to information obtained directly from the project owner, the wind park consists of two phases. The technical specifications of Pretul I and Pretul II are presented in Table 2.

Parameter	Pretul I (2017)	Pretul II (2024)
Turbines	14 × Enercon E-82 E4	1 × Enercon E-126 + 3 × Enercon E-138
Hub height	78 m	86 m (E-126), 110 m (E-138)
Rotor diameter	82 m	126 m (E-126), 138 m (E-138)
Tip height	119 m	approx. 149 m (E-126), approx. 179 m (E-138)
Rated capacity per turbine	3.0 MW	4.0 MW (E-126), 4.26 MW (E-138)
Total installed capacity	42 MW	16.6 MW (some sources cite 16.78 MW)
Estimated annual electricity production	84,000–90,000 MWh	approx. 40,000 MWh
Equivalent house-holds supplied	approx. 22,000–26,000	Not specified

Table 2: Technical Specifications of Pretul Wind Park Phases

Currently, the wind park comprises 18 turbines with a total installed capacity of 58.6 MW[1]. En- vironmental considerations have been integral to the project's design and execution from the outset. Key biodiversity enhancement measures include the restoration of 40 hectares of habitat specifically tailored for black grouse and capercaillie, mitigating risks such as habitat fragmentation and disturbance. In addition, more than 1,500 native trees, including fir (Abies alba), sycamore (Acer pseudoplatanus), and mountain ash (Sorbus aucuparia), were planted to promote reforestation and create wildlife corridors, surpassing the mandatory ecological compensation requirements under Austrian environmental regulations (ÖBf, 2016a).

These initiatives were guided by comprehensive baseline ecological studies and fully incorporated into the Environmental Impact Assessment (EIA) process, with targeted strategies to reduce collision risks for birds and bats.

In parallel, the Pretul Wind Park generates substantial community and regional benefits, particularly by enhancing sustainable tourism in the Hochsteiermark area. Infrastructure improvements include scenic hiking trails, mountain bike routes, the Peter Berger lookout platform, and upgrades to the Roseggerhaus refuge. These features promote outdoor recreation with minimal ecological impact, incorporating sensitive design elements such as elevated footbridges and visitor platforms in vulnerable moor zones like Schwarzriegelmoos. Such measures not only stimulate local economic activity but also raise

1 This installed capacity is sufficient to supply approximately 30,000–35,000 average Austrian households with electricity per year (based on average annual consumption)

public awareness and support for renewable energy and conservation. Ongoing monitoring has demonstrated net-positive biodiversity outcomes, including population peaks for indicator species such as black grouse, while challenges like increasing winter tourism pressures highlight the need for adaptive, long-term management strategies (ÖBf, 2024). Overall, the Pretul Wind Park serves as a practical case study, illustrating how high-altitude wind energy developments can achieve alignment with renewable energy targets, deliver measurable biodiversity gains, and contribute to sustainable regional development.

4 Results

This section provides an overview of the evaluation results, followed by a detailed breakdown of performance within each thematic cluster.

4.1 Evaluation overview

The evaluation of the Pretul Wind Park's biodiversity enhancement measures against the 10 IUCN Good Practice Principles reveals a mixed performance. Seven principles are fully met, while the remaining three are only partly met. No principle is completely missing (see Table 3).

No.	Principle	Assess
01	Target biodiversity enhancement actions on components of biodiversity directly linked to, associated with, or affected by the project.	Met
02	Consider approaches for biodiversity enhancement early in the project cycle.	Met
03	Ensure biodiversity enhancement measures are evidence-based.	Met
04	Establish biodiversity baseline at an early stage in the project cycle.	Met
05	Ensure biodiversity enhancement measures are additional to any measures proposed in relation to mitigating impacts according to the mitigation hierarchy.	Met
06	Ensure biodiversity enhancement actions are measurable with clearly defined goals and outcomes.	Met
07	Identify and scope biodiversity enhancement measures through a collaborative and participatory process of stakeholder engagement.	Partly met
08	Plan to implement biodiversity enhancement measures within a timeframe relevant to the project concerned.	Met
09	Ensure appropriate management, monitoring and reporting requirements are implemented for biodiversity enhancement measures.	Partly met
10	Plan for biodiversity enhancement outcomes to be sustained in the long-term, and ideally in perpetuity, to deliver a lasting legacy from a project.	Partly met

Table 3: Results of the Evaluation

4.2 Foundational Planning and Scoping

Assessment: Principle met

This category covers the essential preparatory steps for effective biodiversity enhancement: targeting actions on biodiversity components directly linked to, associated with, or affected by the project (Principle 1); ensuring all measures are grounded in robust scientific evidence and site-specific data (Principle 3); and establishing comprehensive baselines early in the project lifecycle to support meaningful monitoring, outcome evaluation, and adaptive management (Principle 4). Together, these principles ensure that enhancement is focused, scientifically credible, and rooted in a reliable pre-project understanding of conditions, maximising the likelihood of delivering genuine, attributable gains in complex alpine ecosystems such as moorlands and grasslands.

The Windpark Pretul project effectively targeted enhancement measures at biodiversity components directly linked to or affected by the wind farm, consistent with Principle 1. Key actions focused on protecting and improving sensitive habitats impacted by construction, operation, and associated infrastructure. A prominent example is the protection of the Schwarzriegelmoos raised bog through elevated footbridges and visitor platforms designed to minimise trampling and disturbance in this vulnerable moorland area.

Targeted habitat improvements also addressed risks to black grouse, a priority species in the alpine zone near turbines and disturbance-prone areas. These included selective forest thinning to create open flight corridors and lekking areas, as well as broader habitat enhancements to reduce fragmentation and disturbance from wind infrastructure and rising recreational use.

In line with Principle 4, a comprehensive biodiversity baseline was established early during the EIA process, with key surveys conducted in 2013–2014 and referenced in approvals finalised in December 2014 for the initial phase. The baseline included ornithological assessments (including black grouse populations), bat surveys, moorland habitat mapping, wildlife corridors, and soil/vegetation conditions. These data informed the design of both mitigation and enhancement actions (Amt der Steiermärkischen Landesregierung, 2014, 2018).

All enhancement measures were firmly evidence-based (Principle 3), drawing on specialist ecological reports, pre-construction surveys, and ongoing monitoring. For example, long-term black grouse monitoring, conducted by ÖBf in collaboration with BOKU, demonstrated positive trends, including a population peak around 2020 despite operations beginning in 2016/2017, with birds continuing to use the area and exhibiting lekking (balz) activity near turbines. These results, reported in 2021, confirmed the effectiveness of habitat improvements and the population's good condition even under increasing winter tourism pressure (ÖBf, 2021).

Information from the project owner interview further confirmed that all proposed actions were locally specific, directly tied to identified sensitivities (e.g., moor vulnerability and grouse habitat needs), and integrated into planning from the scoping and EIA stages onward. This proactive, evidence-driven approach ensured that enhancement efforts were precisely aligned with the project's alpine context and potential impacts, fully satisfying Principles 1, 3, and 4.

4.3 Timely Integration & Implementation

Assessment: Principle met

This category focuses on embedding biodiversity enhancement into the project timeline at the earliest feasible moment and executing measures within ecologically and operationally appropriate schedules. Principle 2 requires that voluntary enhancement opportunities are actively identified and incorporated early in the project cycle, ideally during scoping, feasibility, or design phases, rather than deferred to later stages where flexibility is limited and costs rise. Principle 8 requires implementation to be scheduled so that actions have sufficient time to establish, mature, and deliver observable benefits in alignment with construction, commissioning, and operational phases. Prioritising early consideration and realistic timing prevents enhancement from becoming an afterthought or retrofit, enhancing effectiveness, cost-efficiency, and ecological credibility in long-lifecycle infrastructure projects such as alpine wind farms.

Biodiversity enhancement measures were proactively considered and integrated early in the Windpark Pretul project, fully aligning with Principle 2. Habitat improvements for black grouse and capercaillie, along with moorland protection and renaturalisation efforts, were incorporated during EIA preparation and consistently extended to subsequent phases, demonstrating sustained commitment from scoping onward.

Enhancements were grounded in detailed baseline studies and pre-construction planning conducted in 2013–2014. Implementation closely followed the project lifecycle and ecological requirements, satisfying Principle 8. For the original phase:

Moor renaturalisation at Schwarzriegelmoos (removal of invasive vegetation, hydrological restoration, grazing-exclusion fencing, and protective infrastructure such as footbridges and visitor platforms) began in 2016, supported by collaborative "Umweltbaustelle" activities involving volunteers, mountain rescue, and youth groups (ÖBf, 2016b).

- Key infrastructure elements, nature trails, the mountain bike route through the moor, and visitor platforms, were completed between 2018 and 2019, with the Schwarzriegelmoos platform officially opened in 2018 and informational installations finalised by autumn 2019 (ÖBf, 2017).

- Habitat improvements for black grouse, including selective forest thinning for open flight corridors and lekking areas, were executed during and immediately after construction (2015–2017), with ongoing monitoring confirming effectiveness (e.g., population peaks around 2020 and sustained lekking near turbines despite operations starting in 2017) (ÖBf, 2021; EUSTAFOR, 2017).

These timelines ensured enhancement measures were delivered contemporaneously with construction impacts, enabling rapid ecological recovery in a sensitive alpine environment. For the Pretul II extension (operational since February 2024), similar measures, additional habitat enhancements for Black Grouse (Birkwild) and Capercaillie (Auerwild), amphibian ponds, and old wood islands (Altholzinseln), were implemented during the 2023 construction period (assembly completed by October 2023, grid connection in early 2024), further illustrating timely integration.

The Project owner interview (ÖBf, 2026) confirmed that enhancement planning was embedded from the earliest stages, with measures timed to align with alpine weather constraints and ecological sensitivities (e.g., avoiding breeding-season disturbance). This approach minimised delays while maximising ecological relevance, supporting species recovery and habitat integrity across project phases. Overall, the Pretul Wind Park demonstrates exemplary timely integration and implementation of biodiversity enhancements throughout its lifecycle.

4.4 Beyond Mitigation: Additionality and Measurability

Assessment: Principle met

This category centres on upholding the distinction between mandatory impact mitigation and voluntary biodiversity enhancement while guaranteeing that any positive outcomes can be objectively demonstrated and attributed to the project. Principle 5 stipulates that enhancement actions must be strictly additional, i.e., they must exceed and remain separate from any measures already required or proposed to avoid, minimize, restore, or offset the project's adverse effects on biodiversity in accordance with the established mitigation hierarchy. Principle 6 demands that enhancement initiatives are structured around explicit, quantifiable objectives, with well-defined indicators, measurable targets, and clear criteria for assessing success, thereby enabling transparent tracking, independent verification, and credible reporting of net biodiversity gains over time. By enforcing these two requirements, the principles protect the credibility of enhancement claims, prevent the conflation of compensatory and additive actions, and provide a robust scientific basis for evaluating whether alpine wind projects such as Pretul genuinely contribute to broader nature-positive goals beyond legal compliance.

The Windpark Pretul project adheres to the mitigation hierarchy, as documented in project materials and operator (ÖBf, 2026). In addition to mandatory mitigation and compensation obligations required under the Environmental Impact Assessment EIA process and Austrian regulations, several enhancement measures were implemented that go beyond what was strictly prescribed to offset project impacts. These voluntary, additional actions, explicitly described by the project owner as exceeding regulatory requirements, include (ÖBf, 2016b; SuisseEole, 2021):

- Advanced habitat improvements for black grouse and capercaillie: establishment of guiding structures for black grouse to facilitate movement and lekking, intensive thicket management, selective thinning to create open flight corridors, and widespread retention of old wood through secured natural regeneration, while preserving individual veteran trees as biotope trees. These actively enhance structural diversity and habitat quality in ways not mandated for impact offsetting.

- Long-term monitoring programs for target species: black grouse monitoring in cooperation with the University of Natural Resources and Life Sciences, Vienna (BOKU), running through the end of 2026; and capercaillie monitoring conducted jointly with "Büro am Berg" (specialists in wildlife ecology and landscape planning). These collaborative, science-based programs extend beyond typical post-construction compliance monitoring.

Other documented enhancements, comprehensive renaturalisation of the Schwarzriegelmoos raised bog (removal of invasive overgrowth, hydrological restoration, grazing-exclusion fencing, protective footbridges and platforms), reforestation with over 1,500 native trees, and creation of wildlife zones, were framed in project communications as exceeding baseline requirements, with investments underscoring their voluntary nature. The project owner explicitly highlighted that substantially greater financial resources were allocated to these biodiversity measures compared to a standard wind project, with the additional expenditure oriented toward securing long-term ecological benefits beyond short-term compliance (ÖBf, 2021).

These measures satisfy Principle 5 by demonstrating clear additionality: they provide benefits above and beyond the avoidance, minimization, and compensation steps required to address direct project impacts (e.g., habitat fragmentation, disturbance, or moor vulnerability).

Regarding Principle 6, the actions are supported by measurable goals and outcomes through established monitoring. For black grouse, multi-year population monitoring (in partnership with BOKU) has delivered concrete, quantifiable results: despite operations starting in 2017, the population remained in good condition and reached a recorded peak in 2020, with active lekking behaviour observed across the site, including near turbines. This provides direct evidence of net gains in population size and habitat use. Similar structured monitoring for capercaillie ensures ongoing assessment of outcomes.

Information obtained directly from the project owner interview confirms these as additional enhancements with defined, tracked objectives (e.g., population trends, habitat quality improvements). Publicly available reports and monitoring summaries further support transparency and measurability, particularly for flagship species like black grouse (SuisseEole, 2021; ÖBf, 2021). While not every minor action has exhaustive public indicators, the key enhancements, especially species-specific monitoring and habitat improvements, are demonstrably goal-oriented and results-documented, fully meeting the principle's requirements for clear, measurable biodiversity gains.

Overall, the Pretul Wind Park exemplifies strong performance on additionality and measurability, with voluntary over-delivery backed by scientific collaboration and empirical evidence of positive outcomes.

4.5 Engagement and Oversight

Assessment: Principle partly met

This category emphasises inclusive, participatory processes for identifying and scoping biodiversity enhancement opportunities and the establishment of structured, accountable systems for long-term management, monitoring, and reporting. Principle 7 requires that enhancement measures be developed through genuine collaborative stakeholder engagement, incorporating the knowledge, perspectives, and priorities of local communities, conservation experts, scientific institutions, authorities, and other relevant parties to ensure measures are contextually appropriate, socially legitimate, and ecologically sound. Principle 9 requires dedicated long-term management arrangements, scientifically credible monitoring protocols, and transparent reporting obligations tailored to the enhancement actions, enabling adaptive management, objective evaluation of effectiveness, and public accountability for claimed outcomes. Together, these principles transform enhancement from a unilateral technical exercise into a shared, governed process better positioned to deliver credible, enduring benefits in multi-stakeholder alpine settings where land-use conflicts, ecological sensitivities, and public expectations intersect.

The Windpark Pretul project incorporated elements of collaborative engagement in scoping and implementing enhancement measures, consistent with Principle 7, though the process was primarily focused on regulatory and local practical partners rather than broad participatory involvement. Formal stakeholder input took place during the EIA procedure, involving statutory authorities (e.g., Amt der Steiermärkischen Landesregierung), hunting rights holders, local municipalities, and ecological/wildlife experts who contributed to baseline surveys, impact assessments, and measure planning.

On-the-ground collaboration was evident in key implementation activities. For the Schwarzriegelmoos moor renaturalisation, Österreichische Bundesforste (ÖBf) organised an "Umweltbaustelle" in 2016 in partnership with Bergwacht (mountain rescue) and Steiermärkische Landjugend (rural youth organisation). This involved approximately 30 volunteers (ages 16–70) in hands-on tasks such as removing invasive vegetation, restoring hydrology, fencing against grazing, and preparing protective infrastructure. These efforts were supervised by ecologists and directly shaped the practical execution of moor protection (ÖBf, 2016b).

Tourism-related enhancements—including mountain bike routes (Wind+Bike Park Pretul), hiking trails, visitor platforms, and signage, were developed in cooperation with the regional tourism association. As confirmed in the project owner interview, this partnership was voluntary but pursued for its benefits in directing visitors along designated paths to minimise disturbance while supporting local economic interests. Adaptive management, such as temporary quiet periods and routing visitors away from sensitive wildlife, reflects ongoing coordination with tourism stakeholders.

However, direct participation by independent environmental NGOs in identifying, scoping, or designing enhancement measures appears limited. This narrower focus on regulatory authorities, local implementers, and tourism partners means the process was collaborative in a targeted, regional sense but falls short of the broader participatory inclusion advocated by Principle 7.

For Principle 9, ÖBf maintains overall management responsibility as operator and landowner. Structured monitoring programmes provide measurable tracking of key outcomes. Flagship results are publicly reported via ÖBf press releases and communications (ÖBf, 2021, 2024). While not every detail receives exhaustive annual public disclosure, flagship outcomes and adaptive responses demonstrate accountability and responsiveness to pressures such as rising winter tourism (ÖBf, 2021).

In summary, the project partly meets Principles 7 and 9: it achieves effective collaboration and strong monitoring/reporting through practical, regionally focused partnerships and scientific oversight, but the limited involvement of independent environmental NGOs constrains the breadth of participatory scoping, particularly in a project emphasising biodiversity enhancement in a sensitive alpine area. This targeted approach suits the local context but does not fully align with the principle’s emphasis on inclusive, diverse stakeholder processes.

4.6 Long-term Sustainability

Assessment: Principle partly met

This category emphasises the need to secure the permanence of biodiversity enhancement outcomes, ensuring they endure well beyond the project’s active phases and ideally in perpetuity. Principle 10 requires proactive planning for long-term sustainability through mechanisms such as secure management arrangements, dedicated funding, legal safeguards, or integration into ongoing land-use frameworks, so that benefits persist during operation, after decommissioning, and into the future. By prioritising lasting legacy over temporary gains, the principle addresses a key risk in infrastructure projects, loss of enhancement value once resources or focus shift, and aims to create attributable, enduring positive contributions to biodiversity in sensitive alpine ecosystems.

The Pretul Wind Park demonstrates partial alignment with Principle 10. Several implemented enhancement measures, such as the comprehensive renaturalisation of the Schwarzriegelmoos raised bog, habitat improvements for black grouse and capercaillie, and reforestation with native species, are inherently self-sustaining or low maintenance once established, suggesting potential for benefits to persist well beyond the current operational phase (ÖBf, 2016b, 2021). Ongoing species monitoring programmes and the operator’s long-term stewardship role as Österreichische Bundesforste (which manages large areas of public forest land) provide some informal continuity for key actions (ÖBf, 2024).

However, no explicit, formalised provisions for perpetual or post-decommissioning monitoring, legally binding commitments, dedicated endowment funds, or integration of enhancement outcomes into binding land-use or conservation instruments were identified in publicly available documentation or operator statements. The planning horizon for most measures appears tied to the wind farm's operational lifetime rather than deliberately designed for indefinite duration. While the third-phase extension and the operator's stated commitment to alpine renewable energy scaling indicate continued site attention, these do not yet constitute structured, enforceable mechanisms to guarantee maintenance, adaptive management, or monitoring in perpetuity after eventual decommissioning.

Consequently, while the project achieves meaningful medium- to long-term delivery through ecological design and institutional continuity, it falls short of the principle's aspiration for explicit, secured perpetual legacy planning. Strengthening this aspect, e.g., through a dedicated biodiversity legacy fund, formal long-term management agreement, or explicit post-decommissioning commitments, would elevate performance toward full compliance in future phases or similar alpine projects.

5 Discussion

The Pretul Wind Park stands out as a comparatively strong example of biodiversity enhancement in alpine onshore wind development, achieving full compliance ("Met") with seven of the ten IUCN Good Practice Principles, specifically those related to foundational planning and scoping (Principles 1, 3, 4), timely integration and implementation (Principles 2, 8), and beyond-mitigation additionality combined with measurability for priority species (Principles 5, 6). This performance is underpinned by early, evidence-based targeting of site-specific sensitivities (e.g., Schwarzriegelmoos moor and habitats for black grouse Lyrurus tetrix and capercaillie Tetrao urogallus), proactive integration of voluntary measures during EIA scoping and construction phases, substantial additional investment beyond regulatory minima, and scientifically credible monitoring that has yielded tangible positive outcomes, including a documented black grouse population peak in 2020 with sustained lekking near turbines (ÖBf, 2021; SuisseEole, 2021). These strengths illustrate that it is feasible, even in high-altitude, ecologically complex settings, to reconcile renewable energy expansion with meaningful net-positive biodiversity contributions when enhancement is treated as an integral project objective from the outset. The project's emphasis on self-sustaining habitat restoration, coupled with collaborative long-term monitoring (e.g., BOKU partnership), provides empirical proof of concept for alpine contexts where habitat fragmentation, disturbance, and recreational pressures intersect with wind infrastructure (ÖBf, 2021). At the same time, the assessment reveals consistent partial performance ("Partly met") on stakeholder engagement and management/oversight/reporting (Principle 7,9), and long-term legacy (Principle 10). Engagement, while effective in a pragmatic, regionally focused manner (EIA authorities, local partners, tourism associations, volunteer activities), lacks broader, systematic inclusion of independent environmental NGOs. Oversight and reporting are robust for flagship species during operational phases but remain largely operator-led. Most critically, long-term sustainability falls short of the IUCN aspiration for perpetual or post-decommissioning security: no dedicated legacy funds, binding perpetual management agreements, or explicit integration into conservation instruments were established. In the interview with the project owner (ÖBf, 2026), key challenges specific to alpine renewable energy projects were discussed. The operator noted that stricter rules and heightened wildlife protection requirements in alpine areas make it significantly harder to build wind turbines compared to lower-elevation sites, leading many developers to avoid these challenges altogether. Another major difficulty lies in accurately predicting future impacts on animal behaviour and populations, not only within the project site but also in surrounding areas, due to complex external factors like heavy snowfall, increasing winter tourism pressures, and potential climate-driven changes (ÖBf, personal communication, 2026). The operator emphasized a solution-oriented mindset, highlighting that Pretul has succeeded well thanks to deep local knowledge and comprehensive precautionary wildlife measures. To better interpret animal responses amid these uncertainties, additional monitoring was implemented beyond standard requirements, with measures extended to adjacent areas to improve robustness and predictive capacity. These perspectives help explain the project's partial gaps: the alpine environment inherently amplifies uncertainties in long-term outcome attribution and permanence, where external variables complicate reliable forecasting and necessitate adaptive, precautionary strategies. While Pretul mitigates many risks effectively, the absence of formalized perpetual safeguards reflects common constraints in alpine wind projects, regulatory timelines, project-bound financing, and the practical difficulties of securing indefinite commitments (ÖBf, personal communication, 2026).

6 Conclusions

This case study demonstrates that the Pretul Wind Park performs strongly against the 10 IUCN Good Practice Principles for biodiversity enhancement (IUCN, 2024), but falls short of full alignment.

First: It demonstrates that onshore wind projects in alpine environments can achieve substantial alignment with the IUCN Good Practice Principles for biodiversity enhancement (IUCN, 2024), particularly in early-cycle planning, timely implementation, additionality, and measurable outcomes for priority species. By embedding voluntary, evidence-based measures that exceed mandatory mitigation, such as comprehensive moor renaturalisation, targeted habitat improvements, and science-backed monitoring, the project delivers verifiable net-positive contributions despite the ecological sensitivities and technical challenges of high-altitude deployment.

Second: However, gaps remain in broader stakeholder inclusivity, independent oversight, and, most notably, long-term legacy planning. The absence of explicit perpetual mechanisms leaves enhancement outcomes vulnerable after the wind farm's operational life, limiting the project's ability to fully realise the IUCN's vision of a lasting biodiversity legacy.

Third: The findings carry important implications for alpine renewable energy spatial planning across Europe. First, they confirm that meaningful biodiversity gains are achievable under existing frameworks when enhancement is prioritised from the outset and supported by elevated investment and scientific collaboration. Second, they highlight the need for policy and regulatory evolution to incentivise or require stronger perpetual safeguards (e.g., legacy funds, conservation covenants, post-decommissioning commitments) and more inclusive stakeholder processes. Third, the planned third-phase extension (EIA submitted November 2025) represents a critical opportunity to close remaining gaps by adopting untapped IUCN-recommended measures—such as bat- and bird-friendly operations, landscape connectivity enhancements, and ecosystem-wide monitoring, and formalising enduring governance structures.

Last: Scaling the strengths observed at Pretul, while systematically addressing the identified limitations, could significantly advance the dual goals of decarbonisation and biodiversity recovery in mountainous regions. In doing so, alpine wind projects could move from compliance-driven mitigation toward genuine, nature-positive contributions that support both climate and biodiversity targets in an era of converging crises.

In conclusion, the Pretul Wind Park illustrates that well-executed, evidence-based biodiversity enhancements can coexist with onshore wind development in sensitive alpine ecosystems, delivering real net gains, most visibly through the documented recovery and peak of the black grouse population and the successful renaturalisation of the Schwarzriegelmoos moor. Yet the project's partial performance on additionality, measurability, inclusive engagement, comprehensive monitoring, and perpetual legacy planning reveals systemic gaps typical of current European frameworks, where enhancements remain largely tied to compensation obligations rather than voluntary ambition. Strengthening spatial development strategies in Austria and beyond, through mandatory long-term biodiversity commitments, broader stakeholder inclusion, explicit post-decommissioning provisions, and explicit integration of the IUCN Good Practice Principles into EIA and funding criteria, could transform such projects from good practice examples into scalable models of genuine nature-positive renewable energy infrastructure, advancing both climate and biodiversity objectives in high-value mountain regions.

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