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Examensarbete i Hållbar utveckling

Designing for Nature:

Exploring Scientific and Commercial Views on Integrating Biodiversity and Policy into Industrial-Scale Solar Energy Developments in Finland

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Abstract:

Industrial-scale solar energy development is expanding rapidly in Finland, yet its ecological implications, particularly for biodiversity in boreal environments, remain poorly understood. This thesis examines the integration of biodiversity and ecological restoration into the planning and implementation of solar parks in Finland. Drawing on semi-structured interviews with solar developers and environmental experts, the research explores how different land types, peatlands, agricultural fields, forests, and wastelands shape both the environmental risks and opportunities of solar energy infrastructure. The findings reveal that peatlands and wastelands offer promising conditions for biodiversity enhancement when restoration practices are applied, while forests pose significant ecological challenges. Key strategies identified include adaptive vegetation management, integration of grazing and pollinator habitats, and site-specific restoration techniques such as sphagnum moss transplantation. However, inconsistent permitting practices and the absence of ecological incentives in the current policy framework limit the uptake of these strategies. The study concludes that aligning solar energy development with biodiversity goals requires standardized permitting processes, ecological compensation mechanisms, and clearer national guidelines

Keywords: biodiversity conservation, ecological restoration, environmental policy, industrial-scale solar energy, land-use planning, sustainable development

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Summary:

As Finland works to fight climate change, solar energy is becoming an increasingly important part of the country’s energy system. Solar parks, large areas with solar panels that generate electricity, are being built at a fast pace across the country. However, while solar energy is clean and renewable, building these parks still affects the land and the nature around them. If we are not careful, we risk damaging the very ecosystems we are trying to protect.

This thesis explores how we can develop solar energy in a way that supports, rather than harms, nature. The research looks at different types of land where solar parks are often built in Finland, such as former peat extraction sites, fields, forests, and wastelands. It asks: How does solar development affect biodiversity in these areas? And how can we design solar parks that help nature recover?

The thesis combines scientific literature with interviews with solar developers and environmental experts to answer these questions. The findings show that some areas, like degraded peatlands, wastelands, and underused fields, can benefit from solar parks if they are managed in the right way. For example, by restoring wetland conditions, planting native flowers for pollinators, or allowing sheep to graze. Forests, on the other hand, are usually not a good place for solar development because they support complex and sensitive ecosystems.

The thesis also highlights that Finland's policies and regulations need to catch up. Permits are sometimes inconsistent, and developers often lack incentives to invest in biodiversity. Better national guidelines, ecological compensation, and support for combining solar energy with nature-based solutions could help.

In short, the shift to renewable energy doesn't have to come at the expense of biodiversity. With smart planning and good policies, Finland has a real opportunity to build solar parks that support both clean energy and a thriving natural environment.

Keywords: biodiversity conservation, ecological restoration, environmental policy, industrial-scale solar energy, land-use planning, sustainable development

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1. Introduction

Sustainable development has long served as a guiding principle for balancing environmental integrity, economic growth, and social equity (WCED, 1987). Within the environmental component of the sustainability discourse, climate change has captured most of the attention over the past 30 years, often overshadowing other environmental issues such as biodiversity loss, chemical pollution, and ocean acidification. As a result, much of the global effort focused on decarbonizing energy systems and promoting low-carbon technologies such as wind, solar, and bioenergy (UNEP, 2019). However, in recent years, biodiversity loss has emerged as an equally urgent planetary crisis. The two challenges, climate change and biodiversity decline, are deeply interconnected, and solving one without addressing the other may undermine long-term sustainability (IPBES-IPCC, 2021).

This recognition has led to a more integrated understanding of sustainable development, in which climate mitigation strategies must also safeguard and restore ecosystems. The Kunming-Montreal Global Biodiversity Framework, adopted in 2022 under the UN Convention on Biological Diversity, exemplifies this shift. It sets global targets not only for halting biodiversity loss but also for promoting nature-based solutions and ensuring that economic activities, including renewable energy expansion, contribute positively to ecological integrity (CBD, 2022).

In this context, the convergence of global crises in the early 2020s, like the COVID-19 pandemic, escalating climate impacts, energy market instability, and geopolitical conflicts, has further highlighted the fragility of both human and ecological systems. While these crises may seem disparate, they share common roots in unsustainable land use, global interdependence, and the degradation of natural buffers against disturbance (Rockström et al., 2009; Folke et al., 2021). Their cumulative impact has accelerated policy action in Europe and beyond.

The global shift toward renewable energy is now widely framed as a pathway to address the climate emergency. The Intergovernmental Panel on Climate Change (IPCC) underscores that limiting global warming to 1.5°C requires rapid, far-reaching, and unprecedented changes in all aspects of society, especially in phasing out fossil fuels (IPCC, 2023). This has catalyzed what is often referred to as the green transition: a structural transformation toward a low-carbon, circular economy built on renewable energy, electrification, sustainable land use, and resource efficiency.

Within this framework, renewable energy technologies such as wind and solar are promoted not only as climate solutions but also as instruments of energy security, economic resilience, and technological leadership. For instance, the European Green Deal and the REPowerEU plan place the green transition at the heart of the EU's economic and geopolitical strategy (European Commission, 2020; 2022). However, while the transition is essential, it also presents ecological and social trade-offs.

The scaling of renewable energy infrastructure requires land and critical raw materials, such as lithium, cobalt, nickel, and rare earth elements, many of which are extracted from ecologically sensitive or geopolitically unstable regions (Hund et al., 2020; Ali et al., 2017). Mining activities linked to renewable technologies can lead to pollution, habitat destruction, and social conflict. Thus, while replacing fossil fuels is urgent, doing so without reinforcing extractive logic or undermining other environmental goals remains a key sustainability challenge. Moreover, if poorly planned, the land-use demands of renewable energy, especially industrial-scale solar and wind installations, can contribute to habitat fragmentation and biodiversity loss. Researchers have warned that climate mitigation should not violate other planetary boundaries, including biodiversity, land-use change, and freshwater integrity (Steffen et al., 2015). Therefore, the green transition must be more than just low-carbon; it must also be nature-positive, socially just, and ecologically restorative (IPBES-IPCC, 2021; Sovacool et al., 2021; Steffen et al., 2015).

In this light, governance mechanisms and policy instruments play a critical role in mediating the trade-offs between energy development and ecological integrity. In the context of land-use planning, tools such as ecological compensation mechanisms and integrated spatial planning can help align solar energy development with biodiversity goals. While this thesis focuses on EIA, compensation measures, and biodiversity incentives, it is worth noting that broader instruments, such as Strategic

Environmental Assessment (SEA), may also support more proactive environmental planning in the future (Desmond, 2007; Fischer and Gonzáles, 2021). Although raw material sourcing is not a central theme here, EU policy frameworks such as the Critical Raw Materials Act also aim to reduce the ecological impacts of supply chains relevant to renewable infrastructure (European Commission, 2023).

In this context, solar energy has emerged as a central pillar of the green transition, and its expansion in Finland has been particularly rapid. Technological advancements and declining costs have made solar photovoltaic (PV) systems the most economically competitive electricity generation option in many regions (IRENA, 2023). By the end of 2024, Finland had installed over 120 megawatts of solar power capacity, nearly half of it within a single year (Renewables Finland, 2025). Projections from Fingrid, the national grid operator, in September 2024 suggest that this could reach up to 16 gigawatts by 2035 (Fig. 1).

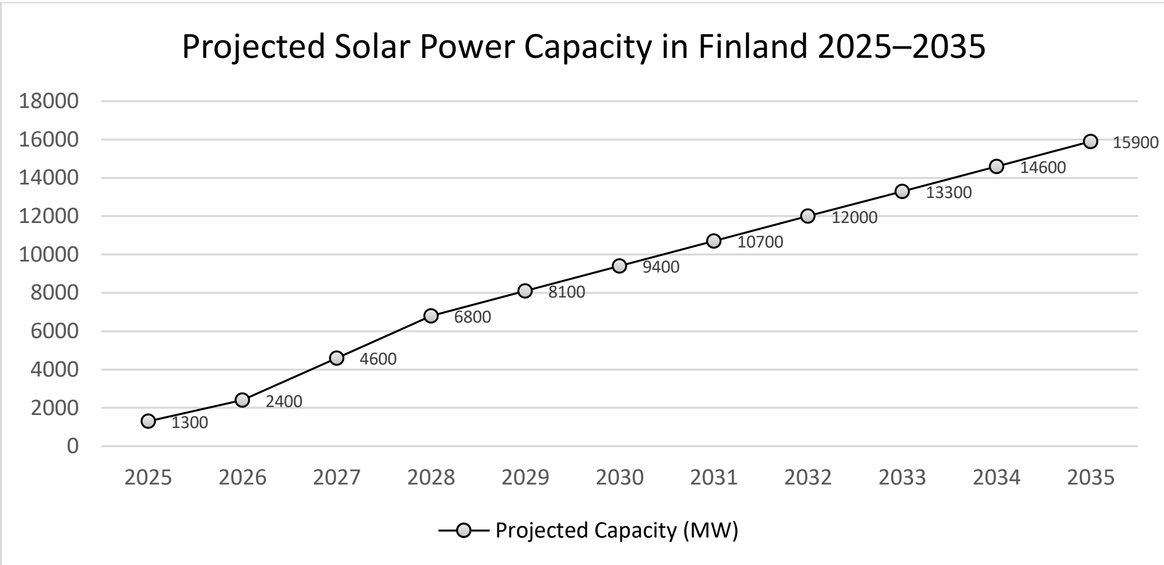

Fig. 1. Solar power capacity projection for Finland 2025-2035. The projected capacity is shown in megawatts (MW). According to data from Fingrid (2024), this figure was created by the thesis author..

1.1. Research Objectives

This thesis explores how biodiversity and ecological considerations can be integrated into the planning and management of industrial-scale solar parks in Finland. As solar energy expands rapidly, there is a growing need to ensure that renewable energy development supports, rather than undermines, ecological resilience. By combining a theoretical framework with qualitative interviews, this study investigates both the environmental impacts, and the practical strategies used or envisioned by actors in the Finnish solar sector. The specific research questions are:

1. How do industrial-scale solar parks in Finland affect biodiversity across different land types (peatlands, agricultural fields, forests), and which design features can mitigate these impacts?
2. How do Finnish permitting and policy frameworks enable or constrain biodiversity considerations in solar energy projects?
3. What actions are being taken, or could be taken, by developers, policymakers, and communities to integrate nature considerations into solar park development in Finland?

The aim is to generate actionable insights for policymakers, planners, and developers while also contributing to the emerging academic discourse on the ecological dimensions of solar energy infrastructure. To address the research questions outlined above, this thesis adopts a qualitative approach that combines theory with empirical insights. The following chapter delves into the theory, familiarizing the reader with the existing literature on the environmental effects of solar parks.

2. Theoretical Framework

To reflect both academic and policy perspectives, the theoretical framework incorporates peer-reviewed literature alongside grey sources such as government reports. However, most of these sources are published in English or Finnish and primarily reflect institutional viewpoints, which may limit the diversity of perspectives. This is addressed in part through expert interviews that complement and contextualize the literature-based analysis. This framework follows a thematic analysis to identify and organize key patterns across the reviewed materials (Braun & Clarke, 2006). The findings are structured into thematic sections, to provide theoretical grounding for the thesis.

The framework's two main areas are the ecological impacts of industrial-scale solar development and the current Finnish policy framework guiding such projects. Ecological aspects include land-use change, biodiversity effects, microclimatic shifts, and potential restoration practises. Due to limited literature specific to Finland, studies from other Nordic and temperate regions with similar landscapes and species were also included. For the policy analysis, the focus is on Finnish permitting practices, land-use regulation, and ecological compensation.

Sources were identified using the Uppsala University library database, Google Scholar, and standard Google searches, particularly for locating Finnish governmental and ministerial publications. Materials included peer-reviewed research, expert reports, government documents, and selected corporate publications.

The keyword combinations used to search for the ecological impacts of large-scale solar development included phrases such as "biodiversity impacts of solar parks," "solar energy in Finland/Sweden/Denmark/Nordics and biodiversity," "solar energy in peatlands/forests/fields in Finland," and "solar park microclimate and vegetation." In some searches the solar was replaced by PV, or photovoltaic term. Additional searches focused on species-specific impacts using terms like "solar energy and amphibians," "solar energy and bees," and "solar energy and sheep." To locate Finnish policy frameworks, a combination of Finnish and English terms was employed, including phrases like "solar power in Finland" and "ELY Centre." Relevant information was also discovered through already familiar documents and found unintentionally through research papers that discussed Finland's policy schemes related to renewables.

The selection criteria prioritized relevance to the Finnish context and direct links to the intersection of solar energy, biodiversity, and nature restoration. Studies set in ecologically distinct areas (e.g., deserts) or focusing on unrelated themes such as sociocultural impacts were excluded to maintain a focused and manageable scope.

The framework is structured thematically, beginning with the ecological consequences of developing different land types, followed by impacts on microclimates and wildlife, design strategies for biodiversity enhancement, and finally, an overview of relevant permitting and policy structures in the Finnish context.

2.1. Land-Use Change and Ecological Impacts

While industrial-scale solar projects require land, concerns about their spatial footprint are often exaggerated. Compared to land used for agriculture, livestock, or recreation, solar park occupies a relatively modest area. For instance, a study by the Great Plains Institute found that in the U.S. Midwest, industrial-scale solar park occupies a negligible proportion of land compared to agriculture (Diffendorfer et al., 2024). Nevertheless, because these parks are typically sited in open areas, they can cause land use changes and ecological impacts depending on prior land conditions and project design.

In the Finnish context, solar parks are most commonly located in former peat extraction areas, agricultural fields, commercial forests, and wastelands. Each of these land types presents distinct ecological risks and opportunities. The following sections examine how industrial-scale solar parks interact with these landscapes, drawing on recent research to identify site-specific considerations for biodiversity and land use planning.

2.1.1. Peatlands

The reduction in energy peat usage in Finland has left numerous former extraction sites available for redevelopment. These sites are often considered well-suited for solar power due to their open structure, distance from residential areas, and degraded ecological condition (Aro et al., 2023; Avonius, 2025). Solar development on such lands aligns with the European Commission's preference for siting renewable energy projects on previously altered or low-conservation-value land.

From an ecological perspective, peatlands are important carbon sinks and biodiversity reservoirs. Integrating solar energy development with peatland restoration, particularly through rewetting and native vegetation recovery, has been proposed as a dual-benefit strategy (Pasanen et al., 2025). Some researchers argue that higher water levels may help control tall vegetation and reduce maintenance costs while restoring ecosystem function (Avonius, 2025).

Avonius (2025) investigates this approach in a field study comparing two former peat extraction sites: one abandoned three years prior (B3) and another ten years prior (A10). Through biogeochemical sampling, vegetation surveys, and simulated photovoltaic shading, the study found greater vegetation richness and moisture retention at the older site. These findings support shallow rewetting and *Sphagnum* moss propagation as potentially viable restoration strategies. However, the study's limited duration and scope focused on only two southern Finnish sites in early successional stages limits its generalizability. Longer-term monitoring is needed to assess resilience, greenhouse gas dynamics, and vegetation shifts under operational solar infrastructure.

While not focused specifically on peatlands, Pasanen et al. (2025) offer a literature synthesis of the ecological consequences of renewable energy infrastructure in Finland. Their analysis cautions that even when sited on degraded land, solar and wind installations can contribute to habitat fragmentation, especially due to fencing and road construction. This is particularly relevant in wetland environments, where such disturbances may interfere with natural successional processes. Taken together, these findings underscore the need for solar-peatland projects to be designed with adaptive hydrological management, long-term ecological monitoring, and a precautionary approach to land-use impacts.

2.1.2. Agricultural Fields

Agricultural fields, particularly those abandoned or underutilized, are another frequent target for solar park development. Although these areas are already heavily modified, they often support relatively low biodiversity due to monoculture practices, soil degradation, and pesticide use (Dahl, 2025; Tilman et al., 2002). When managed ecologically, converting fields into solar parks can enhance biodiversity and ecosystem services.

Recent studies from temperate and arid regions show that solar panel installations can alter hydrological patterns by redirecting rainfall, increasing surface runoff, and affecting nearby aquatic systems (Yavari et al., 2022; Gómez-Catasús et al., 2024). Nevertheless, with appropriate design strategies, such as meadow planting or native vegetation seeding, solar parks may increase local plant and insect diversity, including pollinators (Montag, 2016; Blaydes et al., 2021).

Agrivoltaics, which integrates crop cultivation or grazing with solar production, is emerging as a promising dual-use model. It allows for continued agricultural use of the land while promoting biodiversity and energy generation (Seppälä, 2024). This model may be especially beneficial in regions where land competition between energy, food production, and conservation is high. However, legal, technical, and economic barriers in Finland may limit its scalability in some jurisdictions. The barriers will be discussed later more in-depth in sections 2.4, 5.5.3, and 6.1.2.2.

2.1.3. Forested Areas

Forested areas have occasionally been proposed for industrial-scale solar development in Finland, particularly in regions with abundant commercial forests. However, converting forest land into solar parks raises significant ecological concerns. Unlike managed forestry, which typically allows for regrowth cycles, industrial-scale solar parks results in long-term or permanent land use change. Once cleared, forest areas used for solar installations are not replanted, leading to the loss of mature vegetation, soil structure, and ecological succession processes (Pasanen et al., 2025).

The destruction of tree cover affects both flora and fauna by removing understory habitat, disrupting canopy layers, and fragmenting ecological corridors. These structural elements support a range of species, including forest-dwelling birds, mammals, fungi, and invertebrates. Their removal can significantly reduce biodiversity, particularly in boreal ecosystems where habitat complexity is closely tied to forest structure (Moore-O'Leary et al., 2017; Blaydes et al., 2021). Additionally, the infrastructure and access roads required for construction and maintenance may further fragment habitats and create edge effects detrimental to interior forest species. While Moore-O'Leary et al. draw on a range of ecosystems, including arid regions, their broader focus on utility-scale solar across diverse biomes lends general weight to concerns about habitat fragmentation and wildlife movement. The specific ecological dynamics may differ in Finland's boreal context, but the central principle that large-scale solar infrastructure can disrupt connectivity through fencing and internal layout, is likely transferable.

Forests also serve as vital carbon sinks and play an important role in climate regulation. Replacing forested land with solar infrastructure may undermine climate mitigation goals if the loss of carbon storage exceeds the emissions savings gained through renewable energy production. For this reason, most policy and planning frameworks recommend avoiding forested areas when siting solar parks, and instead prioritize previously degraded or low-biodiversity land types such as former peat extraction sites or agricultural fields (Pasanen et al., 2025; Dahl, 2025).

2.1.4. Wastelands

Wastelands, including former gravel pits, decommissioned industrial sites, and other degraded lands, are being explored for solar energy development in Finland. These areas offer the benefit of repurposing underutilized or environmentally compromised land, thereby reducing pressure on agricultural production and ecologically valuable sites. A recent study assessing land suitability for photovoltaic development in Finland identified wastelands as particularly promising due to their large open areas, limited land-use conflicts, and proximity to infrastructure (Aminitehrani, 2024).

Although still underrepresented in academic literature compared to other land types, these areas have begun receiving institutional support: for example, the European Commission has funded solar projects sited on former gravel extraction areas as part of broader efforts to accelerate renewable energy deployment (European Commission, 2025). These developments underscore the growing recognition of wastelands as a strategic and low-conflict land category in Finland's solar transition. Beyond land selection, the physical presence of solar infrastructure can influence local ecosystems in more subtle but significant ways.

2.2. Ecosystem Responses to Solar Infrastructure

Solar parks, in addition to altering land cover, can cause significant changes in local ecological conditions. These include shifts in microclimates under and around solar panels, as well as disruptions in species movement, behaviour, and habitat connectivity. While some of these changes may present ecological risks, others may provide opportunities for enhancing biodiversity in degraded landscapes.

2.2.1. Microclimate Effects

Solar panels alter light, temperature, and moisture conditions beneath and between panel rows. These changes can create microclimates that deviate from the natural baseline. Studies have documented both positive and negative outcomes, depending on the surrounding ecosystem type.

In arid or sun-intense areas, shading from solar panels has been shown to reduce extreme temperatures and retain soil moisture, which benefits native plant species and pollinators (Sinha et al., 2018; Gasparatos et al., 2017). However, in ecosystems adapted to full sun, such as open peatlands or agricultural fields, the same shading effect can disrupt native vegetation growth and reduce biodiversity (Agha et al., 2020).

In boreal environments like Finland, solar panels may reduce daily temperature fluctuations and modify seasonal moisture patterns in ways that diverge from natural baselines (Armstrong et al., 2016). While some studies have highlighted the potential for positive effects on certain vegetation types, the specific consequences of microclimatic shifts in Nordic ecosystems remain under-researched, particularly in peatlands and open field settings. These gaps underscore the need for more empirical evidence in northern contexts.

2.2.2. Species Movement and Habitat Connectivity

The development of industrial-scale solar parks can alter ecological connectivity and affect both mobile and stationary wildlife species. These impacts depend largely on the landscape context, the physical layout of infrastructure, and management decisions related to fencing, vegetation, and movement corridors.

Large solar projects often require the construction of perimeter fencing for security and against possible vandalism. While these fences protect solar infrastructure, they may unintentionally block access for larger mammals, for instance, deer or moose, contributing to habitat fragmentation and movement disruption (Moore-O'Leary et al., 2017). Smaller species such as amphibians, reptiles, and ground-dwelling mammals may also be affected, particularly if fencing lacks low-level openings or if vegetation corridors are removed during site preparation (Blaydes et al., 2021).

Beyond physical barriers, solar infrastructure contributes to habitat fragmentation by replacing large, continuous patches of habitat with managed and structured surfaces. Roads, cable trenches, and the arrangement of panel arrays can act as movement barriers or alter species interactions. Fragmentation reduces gene flow and population viability, particularly in landscapes where habitat patches are already small or degraded (Crooks & Sanjayan, 2006).

Despite these risks, solar parks also offer opportunities for habitat creation and shelter if appropriately designed. The microclimate under solar panels, typically cooler and less exposed, may benefit species sensitive to heat or light. Ground-level structures can offer shelter to reptiles, small mammals, and insects (Sinha et al., 2018), while the presence of floral vegetation can support foraging activity by birds and pollinators (Blaydes et al., 2021).

However, not all design outcomes are positive. The "lake effect hypothesis" proposes that some birds, particularly waterfowl, may mistake reflective solar panels for water bodies, potentially leading to disorientation, collisions, or failed nesting attempts (Visser et al., 2019). While the scale of this effect is still under investigation, its occurrence emphasizes the need for local ecological assessments during the planning phase, especially in flyway corridors.

To summarise, the impact of solar parks on wildlife and connectivity is highly site-specific. Mitigation strategies, namely vegetated buffers, wildlife tunnels, and modified fencing, can reduce fragmentation, but their success depends on detailed ecological planning and long-term monitoring. To address these ecological risks and opportunities, researchers and practitioners have begun exploring how solar parks can be designed to actively support biodiversity.

2.3. Ecological Design Strategies

While the previous section introduced the general land types considered in solar siting, this section focuses on how these landscape categories relate to biodiversity value and conservation potential.

Thoughtful design and management of solar parks can reduce environmental harm and even improve biodiversity, particularly when projects are sited on degraded or low-value ecological land. In recent years, a growing body of research has focused on how industrial-scale solar parks can be made more ecologically integrated through restoration, habitat creation, and multi-functional land use.

2.3.1. Vegetation, Moss, and Soil Amendments

One of the most promising approaches to improving the ecological performance of solar parks is through vegetation planning and habitat restoration. Studies suggest that replacing bare ground or gravel with native grasses and wildflower meadows can provide critical habitat for insects, pollinators, and birds (Blaydes et al., 2021; Montag, 2016). Low-growing, diverse vegetation reduces erosion, improves soil health, and supports ecosystem functions including pollination and nutrient cycling. While these findings are promising, it is worth noting that Blaydes et al. (2021) focus on UK-based case studies, and their ecological outcomes may not fully translate to boreal ecosystems such as those in Finland. Differences in soil conditions, species assemblages, and climatic regimes suggest the need for local trials before generalizing design recommendations

In regions where traditional meadows have declined, such as Finland, solar parks may provide a rare opportunity to reintroduce endangered grassland habitats. Importantly, nutrient-poor soils are often preferable, as they prevent dominance by aggressive species and allow for greater botanical diversity (Tilman et al., 2002). Over-fertilized sites, by contrast, tend to encourage monocultures and reduce ecological value (Gasparatoes et al., 2017).

Vegetation height must be managed carefully to avoid shading solar panels, and some studies recommend keeping plants under 1 meter high to maintain panel efficiency while supporting biodiversity (Blaydes et al., 2021). Additionally, adaptive vegetation management, like periodic mowing, rotational grazing, or controlled succession, can maintain habitat quality over time.

Recent research highlights the importance of active restoration techniques for enhancing the ecological function of peatlands, particularly in areas repurposed for renewable energy. *Sphagnum* moss plays a central role in peatland recovery due to its high water retention capacity and ability to facilitate carbon sequestration through peat formation (Avonius, 2025). Transplanting *Sphagnum* can accelerate the establishment of vegetative mats that promote long-term restoration success. Additionally, biochar is emerging as a promising soil amendment in peatland contexts. It can improve soil structure, enhance microbial activity, and support *Sphagnum* growth by increasing moisture retention and nutrient balance (Laatikainen et al., 2025).

2.3.2. Pollinators, Grazing, and Habitat Design

There is growing interest in designing solar parks that produce energy and support local biodiversity. Flower-rich grasslands within industrial-scale solar parks have been found to significantly benefit pollinator species such as bees and butterflies, particularly when using native seed mixes (Blaydes et al., 2021). In more advanced designs, solar parks can incorporate diverse microhabitats, such as ponds, rocky outcrops, hedgerows, or deadwood features, to support a broader range of taxa. As discussed by Blaydes et al. (2021), structural elements can enhance ecological complexity and improve the site’s biodiversity value as these habitats offer critical foraging resources and nesting sites.

Livestock grazing, especially with sheep, is also considered an ecologically and economically viable vegetation management strategy. Grazing reduces the need for mechanical mowing and can help maintain floral diversity, especially in areas where nutrient-rich soils might otherwise favor tall, fast-growing plants (Dahl, 2025). Sheep are generally small and docile enough to move around solar panels without causing damage, although predator risks must be managed depending on local wildlife conditions.

2.3.3. Designing for Habitat Connectivity

Large solar parks, especially those with fences, can disrupt wildlife movement and contribute to habitat fragmentation. Physical barriers such as perimeter fencing may prevent larger mammals from accessing historical migration paths, while internal infrastructure (roads, cables, panel rows) can limit the mobility of smaller species (Moore-O'Leary et al., 2017).

To mitigate these effects, some solar park designs incorporate wildlife corridors and permeable or elevated fencing that allow for safe passage (Gomez, 2022; Kalies, 2023). In certain European projects, vegetated strips within the solar field have been used to maintain connectivity for small mammals and amphibians. These strategically placed buffer zones and landscape-scale planning can also reduce the risk of ecological isolation, particularly when solar parks are located near important natural areas or within regional green infrastructure networks (Blaydes et al., 2021; Moore-O'Leary et al., 2017).

Many of the ecological design strategies relevant to solar development, such as habitat mosaics, vegetated buffers, and pollinator corridors can be conceptually situated within the field of landscape ecology. This discipline explores how spatial patterns affect ecological processes, especially in fragmented or multifunctional landscapes (Opdam et al., 2006; Fischer & Lindenmayer, 2007). Concepts such as connectivity, patch structure, and matrix quality provide a useful framework for understanding how solar parks might be designed not only to reduce ecological harm but also to enhance biodiversity at the landscape scale.

While thoughtful design can mitigate many ecological impacts of solar parks, the success of such strategies often hinges on supportive policy environments. The next section examines the regulatory and permitting frameworks in Finland to understand their role in enabling or constraining ecologically informed solar development.

2.4. Permitting and Environmental Assessment

Effective policy and permitting processes are essential for ensuring that industrial-scale solar energy projects align with ecological sustainability goals. In Finland, the regulatory framework for solar development is still evolving, presenting both opportunities and challenges in balancing renewable energy expansion with biodiversity protection.

Unlike other large infrastructure projects, industrial-scale solar parks in Finland are not automatically subject to an Environmental Impact Assessment (EIA). Instead, the need for an EIA is determined by the regional Centres for Economic Development, Transport and the Environment (ELY Centres) on a case-by-case basis (Ministry of the Environment, 2025). According to national guidelines, the EIA procedure is specifically required for solar energy projects that include above-ground energy transmission lines with a voltage of at least 220 kilovolts and a length exceeding 15 kilometers (Ministry of the Environment, 2025). Projects that do not meet this threshold, including most solar parks under 200 hectares in area, typically proceed without a formal EIA unless other significant impacts are identified.

In practice, ecological assessments are often integrated into land-use planning and permitting procedures, with developers required to evaluate the presence of protected species, habitat types, and potential impacts on surrounding ecosystems. These assessments are typically overseen by regional ELY Centres and carried out by external consultants or research institutions (Ministry of the Environment, 2023). While this decentralized model allows flexibility, it may also lead to variability in the depth and quality of ecological evaluations across regions, depending on local practices and interpretations of national guidelines.

The Finnish permitting system currently lacks a unified framework specifically tailored to the ecological risks of solar development. Scholars have highlighted inconsistencies in how environmental regulations are applied and the need for clearer national-level guidance (Dahl, 2025; Laitila, 2023). These inconsistencies may result in delays or uneven consideration of environmental concerns, particularly when local policies or institutional cultures differ between regions. The following chapter outlines the qualitative methodology used to capture these real-world perspectives.

3. Methodology

3.1. Research Design

This thesis adopts an exploratory qualitative research design. The topic on how biodiversity and ecological restoration can be integrated into industrial-scale solar energy development in Finland is still emerging in both academic literature and practice. Because of this, the research does not aim to test predefined hypotheses but instead seeks to generate context-specific insights through open-ended inquiry. This aligns with the characteristics of exploratory research, which is well suited to examining new, complex, or insufficiently understood phenomena (Stebbins, 2001).

A qualitative approach was chosen due to its ability to provide rich, localized, and nuanced understandings of solar development practices and their ecological implications. Given the emergent nature of utility-scale solar development in Finland and the lack of long-term ecological impact data, a qualitative approach allows for in-depth, contextual insights into how actors perceive and implement biodiversity considerations. This is particularly relevant for capturing informal practices, tacit knowledge, and evolving policy interpretations that are not yet documented in official frameworks or quantitative data. As Bryman (2016) explains, qualitative methods allow researchers to explore meanings, processes, and perspectives in rich detail, something especially valuable in policy-relevant fields where stakeholder experiences and interpretations matter.

3.2. Data Collection: Semi-Structured Interviews

This thesis collected primary data through semi-structured interviews with solar energy representatives and environmental experts in Finland. The interviews were conducted via phone, video call, and in person, with durations ranging from 30 minutes to 1.5 hours (see Table 1 for an overview of interview length and distribution).

The interviews followed a semi-structured format, meaning that a set of core questions guided each session, but there was also room for more open-ended discussion. Approximately 80–90% of the interview time was spent addressing the predefined thematic questions, while the remaining portion allowed for exploratory dialogue, mutual idea-sharing, and clarification of complex issues. This approach ensured both consistency across interviews and the flexibility to capture unexpected insights that extended beyond the interview guide (Kvale & Brinkmann, 2015).

Participants were informed about the nature of the thesis and the voluntary nature of participation, and verbal consent was obtained. Interviewees are referred to anonymously in the thesis (e.g., INT1, INT2). While all efforts were made to preserve meaning in the translation process, some nuance may have been lost or adapted when translating from Finnish to English.

3.2.1. Solar Project Developers

Six professionals working in the solar energy industry were interviewed for this thesis. The purpose of the interviews was to understand how solar project developers in Finland incorporate environmental considerations into their work and to explore opportunities for enhancing biodiversity outcomes. Interviewees were selected to provide interdisciplinary perspectives and practical insights often absent from academic research. Their roles included project design (INT3), project management (INT2), environmental consultancy (INT5, INT6), leadership (INT4), and ownership (INT1).

The selection process began by identifying companies active in solar power development in Finland. From this list, relevant individuals were located using company websites and LinkedIn. Most invitations were sent through LinkedIn, accompanied by a brief explanation of the research topic and interview objectives. In cases where LinkedIn contact was not possible, email invitations were used instead. Interview questions were often shared in advance to help interviewees prepare and to encourage deeper engagement with the subject matter.

The key themes covered in these interviews included:

- Site selection and design
- Observed impacts or anticipated ecological impacts
- Legal, regulatory, and other frameworks
- Biodiversity enhancement strategies and examples from practice
- Ideas for future development

The companies represented in the study varied significantly in size, reflecting the range of roles different actors play in Finland's solar energy sector. Based on data from the Finnish Trade Register (Kaupparekisteri), the sample included two companies with approximately 5–10 employees, two with 40–50 employees, and one with 50–100 employees. While all interviewees were employed by these firms, some chose to speak in a personal capacity rather than as official company representatives. This allowed for more open discussion, though it also means that some viewpoints represent individual experiences rather than formal organizational positions.

Due to the variety in company size and the personal perspectives of some interviewees, the results should be interpreted as illustrative rather than representative of the entire sector. Nonetheless, the findings offer valuable insights into how large-scale solar energy development in Finland engages with environmental and biodiversity-related concerns.

3.2.2. Environmental Experts

To gain insights into how solar parks interact with different Finnish environments, interviews were conducted with environmental experts focusing on ecological risks, regional variations, and opportunities for biodiversity enhancement. Two of the interviewees (INT7 and INT9) specialized in peatland ecosystems, while the third (INT8) addressed broader environmental impacts across land types and species. See Table 1 for a summary of the interviewees.

The selection of interviewees did not follow a structured sampling method but was based on relevance and availability. INT7 was identified indirectly through an online article on peatland restoration, which included the contact information of another expert. Due to limited availability, this expert referred me to INT7. INT8 and INT9 were contacted through academic and professional networks, based on recommendations and prior awareness of their work in environmental assessment and conservation.

The expert interviews covered several key areas:

- Environmental impacts of solar parks in various Finnish land types
- Best locations and conditions to minimize the harm to ecosystems
- Restoration techniques and practices for biodiversity enhancement
- Views on regulatory frameworks and implementation challenges

These expert interviews provided critical insights into the ecological characteristics of different land types and informed the evaluation of biodiversity-related practices in solar park development.

3.3. Participants and Sampling Strategy

Participants were selected using non-probability sampling methods, meaning the sample was not chosen randomly and is not statistically representative (Etikan et al., 2016). The main approach was purposive sampling: participants were selected based on their relevance to the topic, particularly their involvement in solar energy development or environmental assessment.

In practice, elements of convenience sampling were also present. Interviewees were contacted through professional networks, LinkedIn, or existing references, often based on availability and willingness to participate. This introduces a degree of bias, as it may overrepresent more accessible or engaged individuals. However, given the exploratory nature of the study, this approach was deemed appropriate for identifying information-rich cases (Patton, 2015).

Table 1. Summary of the interviewees, their roles, the date of the interview, the length of the interview, and the format.

Interviewee	**Role**	**Interview date**	**Duration**	**Format**
INT1	Ownership	10th of Feb, 2025	25:17	Phone call
INT2	Project management	13th of Feb, 2025	1:07:02	In person
INT3	Project design	26th of Feb, 2025	1:11:54	Videocall
INT4	Leadership	25th of Feb, 2025	32:27	In person
INT5	Environmental consultancy	13th of March, 2025	1:10:56	Videocall
INT6	Environmental consultancy	27th of March, 2025	1:02:28	Videocall
INT7	Peatland specialist	1st of April, 2025	1:07:59	Videocall and phone call
INT8	Environmental expert on various topics	7th of April, 2025	1:31:27	Videocall
INT9	Peatland specialist	24th of March, 2025	44:27	In person

3.4. Data Analysis

The interviews were transcribed from audio recordings in Finnish. During transcription, thematic color-coding was used to group related content under five key categories:

- Factors determining the location of solar parks
- Legal and other supportive frameworks
- Environmental impacts
- Examples from Finland
- Ideas for Finland

These categories were initially informed by the structure of the interview questions but were refined during the transcription and analysis process as new patterns and emphases emerged. This approach resembles the reflexive thematic analysis described by Braun and Clarke (2006), which emphasizes flexibility, researcher interpretation, and the active role of the analyst in meaning-making. Rather than applying formal line-by-line codes, color highlighting was used to visually cluster segments of data across transcripts. For example, concerns related to permitting interpretation were consistently highlighted in blue and grouped under the broader theme of “legal and supportive frameworks.” The relevance and coherence of these themes were strengthened by comparing perspectives across actor groups and revisiting the material iteratively throughout the analysis and writing process.

3.5. Data Quality and Trustworthiness

The credibility of the research is supported by a transparent and grounded data collection and analysis process. While the theoretical framework informed the background and structure of the thesis, it was not used to validate or cross-check interview findings. Instead, interview data stands as the core empirical material of the study and complements the theoretical background.

Because the researcher also performed the interviews, transcription, translation, and analysis, there is always a degree of subjectivity in interpreting meaning and emphasis. However, this is a recognized and accepted feature of qualitative research, where the researcher's role is not to eliminate interpretation, but to make it explicit and grounded in the data (Creswell, 2013)

Before presenting the empirical results from stakeholder interviews, the following section synthesizes the key insights drawn from the theoretical framework. This serves as a conceptual baseline for interpreting the practical findings.

4. Theoretical Insights – Anticipated Impacts and Strategies

This section presents the main findings derived from the theoretical framework. While the full framework provided background on ecological dynamics and policy structures relevant to solar energy development, this synthesis distills its key insights into three core areas: land-type-specific impacts, biodiversity-enhancing strategies, and regulatory expectations. These insights offer a conceptual benchmark against which the practical observations from stakeholders can be compared.

4.1. Anticipated Impacts by Land Type

The literature consistently indicates that the ecological effects of industrial-scale solar energy vary significantly depending on the underlying land type. Peatlands are viewed as prime candidates for restoration-oriented solar development. The restoration practices involved incorporating rewetting and sphagnum moss transplantation – practices that have the potential to enhance both carbon storage and biodiversity. However, risks remain around hydrological management and long-term monitoring needs.

Agricultural fields, seen as degraded and biodiversity-poor, are considered to hold latent ecological value. Converting monoculture fields into solar meadows can increase floral and pollinator diversity, especially when native species are reintroduced. Agrivoltaics is frequently presented as a promising, though still emerging, land-sharing model.

Forested areas are generally discouraged for solar siting. The literature emphasizes the long-term ecological costs of forest clearing, including habitat loss, carbon stock reduction, and fragmentation of mature ecosystems. Solar installations in such areas often conflict with both climate and biodiversity goals.

Wastelands, such as former extraction sites and degraded industrial lands, are highlighted as low-conflict, high-opportunity zones. These lands typically lack high conservation value and offer the chance to repurpose underutilized space while minimizing ecological disruption.

4.2. Ecological Design and Biodiversity Strategies

Across all land types, a consistent set of biodiversity-supportive strategies emerges from the literature. First, vegetation management is crucial. Replacing gravel or monoculture grass with native meadow vegetation can enhance pollinator habitats and soil health. In Nordic context, species adapted to low-nutrient soils are in a key position and are recommended to be included in the design of solar parks.

Second, microhabitat creation, referring to pond creation, hedgerows, and deadwood features promotes species diversity. Species benefiting are for example amphibians, birds, pollinators and other insects. Using sheep for grazing is a low-cost, ecologically beneficial alternative to mechanical maintenance. Grazing sheep helps improve soil health and plant diversity by keeping the soil under constant stress from grazing. Fourth, and last, maintaining wildlife connectivity through modified fencing, vegetated corridors, or tunnel passages can help mitigate the barrier effect of solar infrastructure.

These strategies are framed within the broader concept of nature-positive design, aligning renewable energy expansion with ecological restoration rather than minimizing harm.

4.3. Policy and Permitting Expectations

The literature reflected on the growing recognition of the ecological ambitions in solar development, which depends on enabling a policy environment. Several critical expectations emerged. Firstly, consistency across permitting bodies was emphasized as essential. Differences between regional ELY Centres could cause uncertainty and deter biodiversity investments.

Secondly, ecological compensation mechanisms have the potential to internalize biodiversity costs within solar development economics. Lastly, integrated environmental assessments could help deter biodiversity blind spots in rapidly scaling infrastructure.

Collectively, these insights construct a normative model of solar development that is not only low-carbon, but also ecologically restorative. The following section assesses how these expectation align, or diverge, from current practises and perspectives within Finland's solar sector.

5. Empirical Insights – Perceived Impacts and Practical Approaches

This section presents findings from interviews conducted with solar developers and environmental experts. These perspectives provide practical context to the issues raised in the literature and help explore how biodiversity is currently addressed in Finnish solar park development.

The interviews offer insights into land selection, permitting challenges, ecological risks, and restoration opportunities. The themes are organized to reflect the main research questions and highlight both common practices and differing viewpoints across stakeholder groups.

5.1. Site Selection and Land Considerations

The site selection is not a straightforward task for planners and developers of solar parks in Finland. A solar power project involves many factors, and the overall outcome is influenced by these components. Interviewee INT2 explained that in Finland, geographic data is readily available, and a variety of sources are utilized in the early stages of projects to enhance feasibility. However, there are instances where a project might fail, or the original plans may need to be adjusted. Not all data is always accessible, and unexpected issues can arise, as much of the work is conducted during the planning phase when mapping out areas. If a protected species is present in the area, a permit must be obtained to relocate it.

Several limiting factors narrow the options for suitable sites, including designated "no-go" areas such as nature conservation zones, sites currently in use, and historically and naturally valuable significant locations, or if there lives protected species (INT1, INT2, INT3, INT4). Location cannot be too close to areas where people live, nature conservation and leisure areas.

Developers of solar parks require large, continuous expanses of land, which means they must either own these types of land or be able to buy or lease them from landowners. Ideally, the land is easy to build on, flat, uniform, and well-exposed to sunlight. In Finland, areas with the highest solar radiation are typically found along the coast (INT1). Solar power installations in Finland are often built on wastelands, forests, fields, peatlands, and rooftops. In general, wastelands are easier to permit for solar projects (INT6) or when the area is already zoned as an industrial area (INT3). Peatlands are a relatively new option (INT6).

The general guideline is to build solar power installations on already degraded lands. One of the interviewees (INT1) highlighted the discussions around placing solar panels on rooftops instead of on the ground. According to him, this option is not economically viable because the total roof area would need to cover 15,000 hectares of land. Individuals do not have the financial capacity to install solar panels on their rooftops. Additionally, solar parks benefit from economies of scale, while rooftops are uneven and fragmented, which would complicate installation by dividing it into many small sections, involving thousands of buildings, with thousands of stakeholders (INT2).

One very crucial factor is the proximity to the national power grid. The farther a planned industrial-scale solar parks is from the power grid, the more costly and slower the project becomes. Interviewee INT3 noted that one kilometre away from the power grid can cost up to €300,000. As the number of potential risk factors on a proposed solar power site increase, solar power developers are less inclined to initiate a project in a location far away from the grid connection.

5.2. Permitting and Institutional Challenges

The interviews aimed to identify whether there are barriers within policy schemes in Finland that hinder the enhancement of biodiversity in solar parks. "Policy schemes" primarily refer to permitting processes, support policies, and related frameworks. This question was posed to all interviewed participants.

First, the permitting schemes and nature assessments were discussed. In Finland, the permits and nature assessments of solar power are left to the discretion of the regional ELY Centres. They determine what kind of permits are required and influence the course of the project. The main issue related to permitting was that the decisions between ELY Centres vary (INT2, INT3, INT6, INT8). Solar power has developed rapidly in Finland, resulting in “laws lagging behind” (INT3), leading to the invocation of the precautionary principle and demands for further studies (INT2). Another explanation for these differences was the differing “cultures” between the staff in each Centre (INT8). The mentioned cultures were culture of nature conservation, bureaucracy culture, and culture of getting off easy. Differing decisions have an impact on the length of solar projects. INT6 stated that it “would be desirable to know what kind of permitting timelines should be expected for projects”.

In Finland, solar power projects do not require an Environmental Impact Assessment (EIA) if they are under 200 hectares in size. When interviewees were asked whether they consider this a concern regarding the environmental values of the area where a solar power plant is proposed, many did not view the EIA process as particularly relevant in terms of permitting and legislation. They noted that the existing practices for assessing natural values are already quite high (INT5, INT1, INT8). For instance, INT8 remarked, “Nature assessments at industrial-scale solar parks are conducted better than average…and reveal a genuine desire to consider nature” Moreover, there has been a rise in municipal requirements, as landowners who lease their land for solar projects receive substantial rental income, while others face only visual impacts with no financial benefits (INT3). Additionally, the EIA process can take several years, often involving multiple rounds of appeals, making it an undesirable option for many (INT3).

Improvements for the permitting scheme that were raised were uniform guidelines for each regional ELY Centre from the state-level (INT3). In addition, It was believed that guideline for minimum requirements would further reduce the need for EIA if ELY Centres step up their game and were more uniform in their decisions (INT8). There are currently ongoing changes related to the permitting schemes, as the permitting is moving under the construction licence putting the permitting process under one-stop-principle (INT6). “I see it as a good reform…it will likely standardize decisions” (INT6).

Second, on support policies, questions were asked about the availability of incentives for environmental initiatives. The subsidies discussed were primarily related to the overall project rather than being specifically aimed at environmental concerns. In Finland, the Ministry of Economic Affairs and Employment (TEM) offers support instruments for projects that have demonstration value (INT6). It was clarified that while the demonstration value may relate to environmental benefits, it is more commonly associated with new technology. Additionally, subsidies for solar energy have significantly decreased (INT6).

Interviewees were asked for their opinions on incentives, such as subsidies and other legal frames specifically designed to enhance biodiversity at solar power sites. It was noted that solar power developers do not gain financial benefit from restoring or enhancing the biodiversity in their plants (INT7). According to INT3, "In Finland, the current profitability of solar projects is precarious because electricity prices are very low. To achieve profitability, solar construction must be inexpensive. Budgets are tight, and if permits do not require ecological recovery efforts, those costs are often not included in project budgets. It is up to the contractor and developer to decide whether to pursue a more environmentally friendly approach. Hiring someone to manage ecological recovery is always an additional cost.”.

In the view of INT5, support policies always encourage the actors in a certain direction. Whereas INT8 considered the potential subsidies unnecessary. They stated that energy companies should not always expect external funding and should finance nature considerations themselves. INT8 highlighted that the pressure to consider nature should come through companies' Corporate Social Responsibility promises, which nowadays are very good.

However, during the discussion on subsidies, the topic steered to compensation measures. It was brought up that “requiring some form of compensation measures could be beneficial. The company’s interest is to complete the project as easily as possible. If compensation were required, more things would be considered and done, and in the end, it wouldn’t cost that much” (INT3). INT7 added that restoration efforts are usually undertaken as individual projects that require active participation. In Finland, there is a general reluctance to acknowledge the need for environmental restoration, leading to a lack of state-level initiatives or obligations in this area. Though the system for supporting restoration and biodiversity efforts, such as the ecological compensation market, is lacking, these subsidies may risk promoting greenwashing (INT2, INT5, INT7). Another idea raised during this topic was to provide incentives for solar power owners to encourage the joint use and development of industrial-scale solar parks (INT3), such as sowing floral seeds, community gardening and bee farming.

5.3. Perceived Environmental Impacts

All solar projects in Finland are relatively new, and there is a lack of long-term experience. As a result, the interviewees could not provide much insights into the changes they have observed. However, INT3 could share an example of one of their projects in Finland, where a former cereal field transformed into a lush meadow about a year and half after the solar installation was completed. This area was also left to regenerate passively.

INT3 provided insights into the construction period of solar panels: “The installation of solar panels is relatively light, allowing for ample open space between the rows. In Finland, the panels are positioned approximately one meter above the ground to account for snow, leaving space for vegetation under. While the construction phase is typically fast, lasting about 1-2 years, it does cause some disturbances in the project areas. However, once completed, the expected lifespan of a solar plant is 30-40 years, during which the area remains undisturbed, aside from occasional maintenance visits.” INT3 noted that during construction, the area should be preserved to prevent it from becoming a gravel field through the use of geotextiles, as such environments are inhospitable for living organisms. Furthermore, gravel itself has environmental implications, as it is first quarried and then transported to the project site in 80 truckloads for aesthetic purposes.

The impact of power lines constructed outside the solar project sites themselves were discussed with INT2. They noted that solar power projects require connection lines or cables, with underground cables having a lesser impact, though they still clear some land. The main environmental impact of above-ground lines is tree removal, which prevents trees from growing beneath them and fragments habitats. In planning, selecting routes can mitigate impacts; new power lines are usually placed alongside existing ones or next to roads to minimize forest clearing.

The discussion highlighted differences in land types. INT9 noted that meadows and peatlands are easier to manage compared to forests and field soils. Forests can grow trees rapidly, which requires constant clearing and removal of saplings. Similarly, field soil offers such an excellent growing environment that if willow seeds disperse, they can become overrun with saplings in just two years. As a result, both forest and field soils need ongoing management to maintain open spaces, while meadows and peatlands require less intensive care.

If the construction site includes water bodies, ditches, ponds, or rocky or bedrock areas, these areas are typically left untouched (INT3). In the case of peatlands, the impact of construction is minimal because water protection structures were already established during peat production. The water passes through several filtering pools, and its quality has been monitored throughout the peat production process. This monitoring continues during the solar power development (INT5).

During construction, it is likely that the noise will drive the animals away from the area. Once the construction ends and the environment settles, the animals are expected to return (INT2). However, the project areas are often surrounded by wildlife fences, allowing the movement of small mammals but disturbing the movement of larger ones (INT2, INT3, INT6). When asked for the reason for fencing the industrial-scale solar parks, the answers were vandalism and safety (INT2, INT3, INT6), as securing the investment takes the predence (INT3).

Nonetheless, the project sites have green corridors that follow marked migration routes to facilitate the movement of wildlife. If these migration routes are blocked, there is a risk that animals, such as moose, may have to detour around the area and end up on a road, creating potential safety hazards (INT3). INT4 shared insights from their current project in a peatland area, where ditches surround the project site, instead of fences, allowing larger animals to move freely. Additionally, INT3 noted that tree-cutting and clearings in the project area are avoided during bird migration and nesting seasons.

5.4. Peatland Restoration Practices

This section focuses particularly on the context of peatlands in biodiversity enhancement and restoration.

5.4.1. Site Conditions and Feasibility

When planning biodiversity-enhancing actions on peatlands, context-specific strategies are essential due to the heterogeneity of these environments. Interviewees emphasized that restoration is not universally beneficial and must be tailored to local conditions. As INT5 and INT2 pointed out, within a single parcel of land, huge variations can exist, creating unique ecological mosaics that require site-specific consideration. In particular, restoration efforts on thick-peat areas may be more justified, though caution is needed as raising the water level requires careful planning, as overly saturated conditions can hinder restoration outcomes depending on peat depth and site characteristics (INT5, INT2)

However, these sites offer potential as solar construction areas, especially where vegetation, insects, and birds have already been depleted. It was indicated that if the restoration under the panels is completed and the panels are removed in 40 years, the area might resemble restored peatland (INT7). According to INT7, in Southern Finland, most bogs have already been drained and thus offer more potential for restoration than bogs in the North, which are generally more intact due to less forestry pressure. Former peat production areas, especially where all peat has been extracted, may no longer function ecologically as peatlands (INT5). These thin-peat areas benefit more from afforestation (INT5).

5.4.2. Restoration Techniques

A major theme across interviews was water management. Controlled sub-drainage systems can help maintain ideal water levels for both technical and ecological outcomes (INT4). Too much water can hinder vegetation establishment, keep pollinators away, and prevent maintenance (INT4, INT7), while dry conditions risk carbon emissions and slow regrowth. Optimal water levels for restored bogs are about 5–10 cm; at 20 cm, the site becomes too dry, but occasional flooding is beneficial (INT7). Water level fluctuation was seen as particularly advantageous for increasing bird diversity, especially by promoting insect populations that serve as food sources (INT8). However, such practices are rarely implemented despite their ecological benefits (INT8, INT5).

While high water levels are important for the ecosystem, they were noted to interfere with the maintenance activities crucial for the area's primary function: energy production. Concerns were raised regarding logistics and maintenance access when water levels are kept high (INT4, INT5). Additionally, if the soil contains high levels of acidic sulphate, increased water levels could corrode the structures of the solar panels (INT5).

Active restoration efforts were considered important, particularly the transplantation of sphagnum moss, which was noted to form beneficial vegetative mats. INT7 emphasized that simply tossing moss in one location is inefficient, uniform spreading is key. Sphagnum moss thrives under high moisture conditions and contributes to carbon sequestration, making it an ideal species to promote in suitable peatland solar sites (INT7, INT5). Where nearby natural bogs exist, passive regeneration through seed dispersal can occur, though active supplementation accelerates the process (INT7). Techniques like covering mosses with straw to regulate microclimates and moisture balance were also mentioned as effective early-stage interventions (INT7).

Various soil amendments were also discussed. Ash fertilization, commonly used in forests, can boost growth on bare former peatlands without significantly impacting water quality, making it suitable for areas with low nature value (INT7). Additionally, biochar application was noted to enhance sphagnum growth (INT7), further supporting rapid ecological recovery.

5.4.3. Bird Considerations

The relationship between solar infrastructure and birds was considered complex. While solar panels themselves were not seen as major disturbance factors for birds, INT8 responded positively to the posed question regarding a potential increase in collision deaths when panels are situated near water bodies, particularly for species that are already prone to such accidents. But it was highlighted that no mass deaths are expected. Nonetheless, many bird species benefit from the ecological change, particularly in wetlands formed through controlled water management (INT5, INT8). INT8 also expressed concerns about siting solar parks in areas that serve as resting or breeding grounds for migratory birds, particularly Arctic species like barnacle geese, which have changed their migration route to pass through Finland. Especially in South-East Finland, large flocks stop and should be taken into account in solar power plans in the area (INT8).

5.5. Broader Ecological Strategies

Beyond peatland areas, a wide range of ideas were shared and discussed on how solar power sites could be developed into multi-functional landscapes that support biodiversity. Topics ranged from plant and animal species to, ideas of food production and community engagement.

5.5.1. Vegetation and Land Management

It was noted that solar parks can maintain or even enhance biodiversity when planned thoughtfully. For instance, the belief is that a wide variety of species and vegetation types can coexist with solar panels (INT3), provided that the site is not over-fertilized (INT8). In fact, traditional meadows, which are naturally species-rich, thrive on nutrient-poor soils. In contrast, fertile soils were repeatedly associated with a decline in biodiversity due to the dominance of monocultures (INT8). Management practices like maintaining vegetation under one meter high were seen as ideal (INT3), as they prevent shading of panels while still supporting low-growing, ecologically valuable plants such as clover (INT6, INT3). But more interesting vegetation for pollinators should be considered (INT6).

Responsibility for minimizing ecological harm was addressed through examples like tree-by-tree evaluations to avoid unnecessary deforestation (INT3) and client demands to replace felled trees with new plantings (INT3).

5.5.2. Grazing, Pollinators, and Structural Habitats

The integration of grazing animals, particularly sheep, was seen as a practical and ecological management strategy (INT6, INT3). Sheep help reduce soil fertility in nutrient-rich areas, which aligns with the goal of creating diverse meadow-like habitats (INT8). However, concerns were raised about fencing and predator risks, especially in remote areas where sheep could attract wolves (INT5). One interviewee described this risk bluntly as a “sheep buffet” scenario (INT5).

Bees were also highlighted as valuable cohabitants, especially in field-type environments, in light of their global decline (INT2, INT3, INT6). Other forms of biodiversity support included wildflower meadows with local species (INT7), rocky habitats for reptiles and insects (INT6, INT7, INT8), and the creation of ponds or wetlands to attract birds and amphibians (INT3, INT8).

Some species do not just benefit from the nearby waterbodies but can use solar panel structures as nesting shelters (INT9). Innovative habitat ideas included installing stormwater ponds (INT3) or water hollows (INT9), preserving standing and laying deadwood for insect and fungal species (INT7, INT8), and even building islands in ponds to attract protective colonies of black-headed gulls, which are seen as “guardians” for more vulnerable waterfowl species, such as pintail, garganey, tufted duck, and scaup, against common predators such as mink or raccoon dog (INT8).

Design considerations that take animal movement into account were highlighted through an example from the UK, where small mammals were allowed access the area via small tunnels under fences (INT3).

5.5.3. Agrivoltaics Potential

The concept of agrivoltaic systems was frequently discussed, but interviewees emphasized that current legislation in Finland does not support the combination of farming and solar power production (INT2, INT6). While integrating agriculture or berry cultivation with solar energy could help reduce land-use conflicts, the potential for crop production under solar panels is limited due to factors such as shade, low yields, and regulatory challenges (INT3, INT6). However, if energy companies were to offer land rent-free, then low-intensity or experimental agriculture might be a viable way to advance this concept (INT3).

5.5.4. Community Involvement

A question regarding potential community engagement with solar parks was posed directly to some of the interviewees. Some developers mentioned being open to partnerships and suggested that, while electricity production is the priority, they are willing to support other uses as long as they do not interfere with operations (INT2). Suggested activities ranged from public access to wildflower meadows or other plants that are under one meter to be cultivated (INT3) to designated planting strips with planter boxes along fence lines for community gardening (INT6).

Although some form of incentive, and responsibility limits with selected operators was deemed necessary to encourage participation (INT3). Also, fencing is done to keep the area intact, and such a community engagement is at crossroads with this (INT5). And the larger projects are often located off-sides (INT6).

Drawing on both literature and interviews, the following chapter discusses the ecological impacts of solar parks across different land types and assesses practical strategies for biodiversity integration.

The interview findings reveal both practical barriers and innovative ideas emerging from the field. In the next chapter, these insights are synthesized with theoretical perspectives to critically assess how solar parks in Finland can better align with biodiversity goals across different land types.

6. Discussion

This chapter synthesizes insights from the literature and interviews to explore biodiversity implications across different land types, examine the influence of policy and permitting frameworks, and assess the roles of various actors in integrating ecological considerations into solar park development in Finland. While this discussion interprets and contextualizes the findings, the explicit answers to the research questions are presented in the conclusion.

6.1. Biodiversity Impacts and Restoration Potential by Land Type

Industrial-scale solar parks are rapidly expanding across Finland, raising concerns about their potential impact on the environment and biodiversity. Solar parks are built on a range of land types, including peatlands, agricultural fields, forests, and wastelands. Each of these types supports a different type of ecosystem.

This chapter explores the effects of solar parks on biodiversity across these land types and identifies design features that can mitigate potential impacts. It draws on the literature and interview findings, to provide a comprehensive view of how solar parks can be integrated with biodiversity preservation and enhancement efforts.

6.1.1. Peatlands – Restoring While Building

Peatlands offer a unique opportunity to align renewable energy development with ecological restoration goals in Finland. As part of the country’s boreal forests and peatlands, these areas are central to both climate mitigation and biodiversity conservation (Pasanen et al., 2024). However, as the need for renewable energy grows, solar park development on peatland sites raises important questions about the balance between energy production and environmental protection. The growing number of endangered species (Hyvärinen et al., 2019) underscores the urgency of aligning energy expansion strategies with biodiversity preservation.

Solar parks present a unique opportunity to restore peatlands while contributing to Finland's renewable energy goals. When appropriately managed, solar parks can provide the land with a rest period of 30-40 years, allowing for natural processes and improving biodiversity in the area. The restoration of peatlands under solar parks is particularly valuable, as the land is mainly left undisturbed, enabling the recovery of native plant species and the preservation of essential ecological functions, such as water retention and habitat for local wildlife.

Maintaining appropriate water levels during the restoration phase is essential to achieving long-term ecological outcomes on peatland sites. Interviewees emphasized that restoration should be tailored to site conditions, particularly peat depth. Restoration efforts were seen as more justified on thick-peat areas, where there is greater potential for successful rewetting and biodiversity recovery (INT2, INT5).

However, achieving optimal water levels is not without challenges. INT7 and INT9 noted that water levels that are too high may hinder vegetation establishment, especially for sphagnum moss, while excessive fluctuation may destabilize restoration gains. The most favorable conditions appear to be where water levels are kept within approximately 5–10 cm of the surface, allowing for a balance between moisture retention and vegetation development (INT7). Occasional temporary flooding was also considered beneficial. These findings suggest that water level management is a critical, yet manageable, aspect of solar-peatland integration when designed with site-specific needs in mind.

6.1.1.1. Restoration Measures

Targeted ecological restoration methods can significantly enhance the biodiversity value of solar parks located on peatlands. One such method is the transplantation of sphagnum moss (Avonius, 2025), which plays a pivotal role in improving the peatland's ability to capture and store carbon.

According to INT7, sphagnum moss transplantation is an effective method for boosting peatland recovery, as it enhances the growth of peat-forming plants and accelerates the restoration process.

To further optimize the growth of sphagnum moss, biochar can be added to the soil (Laatikainen et al., 2025). This improves soil quality, enhances water retention, and carbon storage, contributing to a more sustainable peatland ecosystem. In addition, covering the area with straws can help maintain moisture levels, by creating a stable microclimate for the moss to thrive. These restorative practices, when combined with low-impact solar park maintenance, can significantly improve the ecological health of peatlands, facilitating both carbon capture and the regeneration of biodiversity.

6.1.1.2. Design Considerations

Effective solar park design can minimize disturbances and support ongoing peatland restoration. Designing solar parks on peatlands requires careful consideration to minimize disturbance and support biodiversity recovery. As mentioned, solar parks offer a rest period for the land, allowing water levels to be managed to support the restoration process.

However, maintenance activities, though minimal, still need to account for the water levels. INT9 emphasized that while nature does not require perfect peace, occasional disturbances during maintenance (such as temporarily lowering the water level) can actually benefit biodiversity. These brief disturbances, such as decreasing water levels for short periods, help introduce dead plant material, which in turn attracts more bugs. The increased insect population draws in birds, enriching the ecosystem by enhancing both vegetation and fauna.

A proposal discussed with developers, such as INT2 and INT5, involves using pontoon walkways during maintenance to prevent unnecessary disturbance to the peatland. These walkways, while costly, offer a potential solution to minimizing the impact of maintenance activities on peatland ecosystems. However, the high cost and occasional nature of maintenance disturbance may mean that this solution is not always practical, and developers should consider whether simpler, less expensive approaches might work.

Equally important, however, is a pragmatic mindset. As emphasized by interviewees like INT8 and INT9, ecological restoration does not have to be perfect to be meaningful. Biodiversity benefits can begin to emerge even with partial recovery, and early successional habitats may offer immediate gains for insects and birds. In a context where environmental degradation is urgent and widespread, waiting for perfect conditions or full scientific certainty may delay needed action. As such, adopting a “do what you can, where you can” approach to peatland recovery under solar parks is not just acceptable - it may be the most realistic and effective strategy available

To conclude, peatlands are invaluable ecosystems that play a crucial role in carbon sequestration and biodiversity conservation in Finland. Solar parks, when designed with careful attention to the ecological needs of these areas, offer a unique opportunity to restore degraded peatlands while contributing to climate goals. Through sphagnum moss transplantation, the use of biochar and straw for microclimate stabilization, and bird-friendly restoration designs, solar projects can significantly improve peatland health.

6.1.2. Agricultural Fields – Challenges and Dual Use Potential

Agricultural fields, while often degraded, offer a promising landscape for biodiversity restoration through industrial-scale solar parks. These areas are among the most common sites considered for industrial-scale solar parks in Finland.

These lands are already modified and generally support lower levels of biodiversity due to monocultures, pesticide use, and soil degradation. However, when managed thoughtfully, solar parks on agricultural fields offer opportunities to enhance biodiversity and restore ecological functions. This section outlines key design strategies, practical challenges, and emerging ideas around dual-use systems and community engagement, drawing from both literature and interview findings.

6.1.2.1. Vegetation and Soil Restoration Potential

One of the clearest ecological opportunities in converting agricultural fields into solar parks lies in restoring vegetation and improving soil health. Strategic vegetation and soil management practices on agricultural lands can enhance biodiversity and ecosystem function. Interviewees emphasized that fertile field soils pose a dual challenge and opportunity. On the one hand, their richness leads to rapid vegetation growth, which may require frequent clearing. INT9 noted that field soils "are such a good growing base that if any willow seeds blow in, in two years it's full of saplings." On the other hand, such growth can be managed ecologically to support meadow-like habitats. INT8 stressed that nutrient-poor soils are actually preferable for biodiversity, as they discourage monocultures and allow more plant species to coexist.

INT3 noted that in a Finnish solar project, a former cereal field transformed into a lush meadow approximately one and a half years after solar installation, even though the regeneration occurred passively. This rapid vegetative recovery is supported by the literature, which suggests that solar parks can increase local plant and insect diversity, particularly when native vegetation is growing (Montag, 2016; Blaydes et al., 2021).

INT3 and INT6 recommended maintaining vegetation under one meter high to prevent panel shading while supporting low-growing plants, such as clover. Moreover, INT6 also suggested more targeted efforts, such as planting flowers beneficial for pollinators, to increase habitat quality further.

6.1.2.2. Agrivoltaics: Opportunities and Barriers

Agrivoltaics, has potential as a land-sharing strategy but faces practical and regulatory constraints in Finland. Sheep grazing was identified as a practical and ecological management tool. Sheep are more reliable in ensuring the integrity of the solar panels compared to goats, which may jump on the solar structures. Sheep are an ecological option for vegetation management and a good way to reduce costs associated with maintenance actions related to vegetation management. INT8 noted that sheep can also reduce soil fertility, which helps support diverse plant communities suited to meadow habitats.

However, more complex agrivoltaics systems, such as integrating crops or berry farming, face substantial challenges in Finland. Interviewees INT2 and INT6 explained that current legislation does not support the combination of solar panels and food production on the same land. For instance, landowners who convert more than half of their agricultural land to solar use may lose access to agricultural subsidies (INT6). As INT3 put it, "While integrating solar energy production and crop or berry farming could help reduce land-use conflicts, the potential for crop production under solar panels is limited due to factors such as shade, low yields, and regulatory hurdles."

INT3 also proposed that allowing rent-free access for low-intensity or experimental agriculture could be a way to pilot agrivoltaics in Finland, especially if supported by changes in the permitting and subsidy structures.

6.1.2.3. Community Engagement Potential

Industrial-scale solar parks on agricultural land can foster local support and multifunctional use through community engagement. Some interviewees saw potential for solar parks on agricultural fields to support community-oriented activities, particularly when located near residential areas. INT2 and INT3 mentioned being open to dual-use ideas, provided they do not interfere with the energy production or compromise safety. Suggested actions included public access to wildflower meadows and community planting initiatives along fence lines (INT6).

However, fencing remains a complicating factor. While it is typically installed to prevent vandalism and ensure operational safety (INT2, INT3, INT6), it may limit opportunities for open community access. Nevertheless, INT6 offered a compromise model involving designated strips for community gardening or floral planting boxes outside the fenced zones.

The thesis also proposes an idea for partnerships with local businesses to overcome certain budgetary constraints of solar projects, as mentioned by INT3. For example, if the industrial-scale solar park planted wildflowers using seeds supplied by local gardeners, it could provide ecological value to the site, brand visibility to the gardener, and positive sustainability messaging for the energy developer. Locals could then be invited to pick flowers or participate in site-related events.

To conclude, agricultural fields are often seen as convenient and low-conflict options for industrial-scale solar parks, but they should be designed to avoid replicating ecological downsides associated with conventional farming. This requires openness for biodiversity-enhancing practices like grazing and native planting. While sheep grazing stands out as the most feasible dual-use approach today, broader agrivoltaics integration will require changes to Finnish policy frameworks. Beyond ecological considerations, industrial-scale solar park on agricultural fields, especially those near towns, offer potential for local engagement. From bee farming to wildflower collection, these initiatives can build public support and deliver social co-benefits. As such, agricultural lands represent an opportunity for multifunctional solar landscapes in Finland.

6.1.3. Forests – Why They Should Be Avoided

Forests are complex ecosystems that provide critical habitat for a wide variety of species, including many that are dependent on the specific microhabitats, canopy cover, and ecological processes found in mature or semi-natural forests. In Finland, forests play a particularly important role in supporting biodiversity, maintaining soil health, regulating climate, and sequestering carbon. As such, converting forests into industrial-scale solar parks can cause significant and often irreversible ecological damage. Unlike managed forestry, which allows for regrowth and cyclical disturbance, solar energy development results in a long-term, or even permanent, land use change that halts forest succession and removes key habitat structures (Pasanen et al., 2025).

The best advice that this thesis can offer when it comes to solar park development and forests is to avoid forests altogether. Forested areas should not be considered as potential sites for solar parks, especially when alternative locations, such as degraded or already-altered lands, are available. Interviewees, including INT2 and INT3, emphasized that forest plots are rarely the first choice for solar developers, and are typically avoided when feasible. Sites like old industrial areas, wastelands, or stretches of land beneath power lines offer lower nature values and fewer conflicts, while still enabling the production of renewable energy. As INT9 pointed out, vegetation beneath power lines is already kept low due to maintenance, and open-habitat species often thrive there. However, even in these locations, shading from solar panels must be considered, as it could displace existing vegetation and species.

The second best advice, if forest areas are to be used despite these concerns, is to minimize ecological impacts through deliberate design and mitigation strategies. These include preserving ecological corridors, planning for species movement, and maintaining biodiversity elements such as deadwood. While these strategies cannot fully compensate for forest loss, they can help to reduce the overall ecological footprint of the project and maintain some level of functionality in the affected habitat.

6.1.3.1. Design Considerations and Mitigation Strategies

If a solar park is to be constructed in or near a forested area, the design must be approached with caution and ecological sensitivity. Large-scale solar parks can occupy up to 200 hectares, and fencing these areas creates a barrier that can disrupt wildlife movement routes and fragment habitats. In landscapes where animals rely on continuous forest cover for food, shelter, and breeding, such fragmentation has negative effects.

First, one key strategy is to incorporate wildlife corridors into the solar park layout. These are planned passages, either through the site or along its edges, that allow animals to move between habitat patches. Without such corridors, forest-dwelling species may be cut off from vital resources or become isolated in shrinking habitat patches. In Finland, as in many other countries, wildlife corridors are already used in road construction projects, for example through tunnels under highways or forested overpasses. The same logic can be applied to solar park planning to maintain ecological connectivity.

Second, the installation of vegetation buffer zones along the periphery of the site can help to soften the edge effects that occur when a natural habitat meets a developed area. These buffers, left as strips of undisturbed forest or shrubland, act as transition zones that provide cover, foraging areas, and nesting habitat. When combined with wildlife corridors, they can reduce the severity of habitat fragmentation and create a more permeable boundary between the solar park and the surrounding ecosystem.

Third, fencing strategies must be reconsidered. While fencing is often necessary to prevent vandalism or ensure safety, enclosing large tracts of land can prevent animals from accessing or leaving the area. Interviewees like INT3 noted that security concerns typically drive fencing decisions. But the question is whether full enclosure is always necessary. In some cases, fencing could be limited to the most exposed sides of a site, like those adjacent to roads, while other edges might be left open or protected by less obstructive barriers, like ditches or trenches. For example, INT4 described a project where trenches were used instead of fences on some sides, allowing larger mammals to move freely. While this might not solve all issues related to habitat fragmentation, it could still reduce some of the ecological barriers created by traditional fencing.

If full fencing is still required, design adaptations such as small tunnels or culverts under the fences can allow smaller animals to pass through. As discussed by INT3, these structures would be particularly useful for species like hares, hedgehogs, or even endangered small mammals that cannot damage the infrastructure but benefit from access to shelter. In fact, fenced industrial-scale solar parks could offer some protection for smaller prey species by keeping out their larger predators. But it must be ensured that the site has enough exits so animals do not become trapped.

Fourth, when forests are cleared for construction, there is often a tendency to completely remove all vegetation, including deadwood. However, standing and lying deadwood is essential for many insects, fungi, birds, and small mammals. Interviewees INT7 and INT8 emphasized that some of this material should be retained or reintroduced. While standing dead trees might be difficult to place among panel rows, they could be left at the site edges. Lying deadwood can be added after construction in areas that do not interfere with maintenance operations or pose fire risks. These simple actions can significantly increase the biodiversity value of the site, even in a degraded state.

One concern raised by few interviewees is the pressure to maximize land efficiency due to the economies of scale in solar park investment. Large projects benefit from lower costs per kilowatt of installed capacity, which creates an incentive to build as big as possible. However, integrating ecological features like wildlife corridors and buffer zones can reduce the available area for panels or increase the land needed for the same capacity. If such elements are not considered early in the planning phase, developers may resist adding them later, as this could compromise financial feasibility. For this reason, ecological design strategies should be part of the initial layout in early planning stages, not added as an afterthought.

In conclusion, forests should not be primary candidates for industrial-scale solar parks due to their high ecological value and the difficulty of restoring what is lost. Nevertheless, where development does occur, solar parks must be designed with the goal of minimizing the harm. Retaining deadwood, rethinking fencing, and ensuring connectivity through wildlife corridors and vegetation buffers can help reduce negative impacts. These actions may not make forest-based solar parks ideal, but they can make them less ecologically harmful.

6.1.4. Wastelands – Underused Potential

Wastelands are often degraded lands with poor environmental value. Here, the potential to build environmentally sound solar projects could be considered easy, as the way is only up. Preparing the land for building solar panels does not require much initial work that would disturb the environment. The land is often a large open area, does not have land-use conflicts, and is often located close to infrastructure (Aminitehrani, 2024). Permitting solar projects is easy (INT6), so the permitting procedure should also be relatively swift.

Solar parks take up a lot of space, but only about half is used efficiently, whereas the rest is open space lacking purpose (other than allowing easy maintenance and not shading on panels). Industrial wastelands considered for solar power in Finland can vary in proximity to urban areas or towns. However, those located closer to towns offer opportunities for community engagement and dual use of the land.

Solar developers were generally open to ideas regarding partnerships and dual-use around the solar parks. Open for the ideas as long as it does not cause harm to the energy production, the solar investments are safe, and the security of the area can be ensured. Ideas for dual use of the land ranged from cooperation in a clear contractual manner with sheep and bee farmers to wildflower meadows with public access and planting boxes by the fencing for community gardening ideas. For example, having sheep in the area would bring benefits for the solar developer as well as would reduce the need for maintenance activities related to keeping the potential hay below the panels. There are dangerously few bees, so combining bees with wildflower plantings would contribute to the overall population of bees and help the environment feel well. Obviously, each idea is dependent on the state of the nature on the site.

Allowing the locals to use the strips for community gardening, or any other ideas presented above, may not bring the company much monetary revenue, but actively taking initiatives for the environment will contribute to the good sustainability promises that many of companies have in their company promises, and also improve the acceptability of the projects among locals. The best argument for the situation is the more we can dedicate already in-use land for dual purposes, the less we need to take space from the pristine environment.

Given their variable and often degraded conditions, wastelands offer a flexible canvas where biodiversity strategies trialed on other land types, such as water hollows, rock piles, or native meadow planting, can be readily applied. These small-scale interventions can help enhance habitat heterogeneity and provide shelter for birds, amphibians, and reptiles. These features are simple to implement and can be adapted across land types, adding ecological value even on otherwise intensively used or degraded land.

Wastelands were described by interviewees as generally easier to permit compared to other land types, particularly when the area was already zoned for industrial use. This regulatory ease, combined with low biodiversity value, makes them attractive from both a development and ecological standpoint. However, the broader pattern across interviews suggests that land selection rarely hinges on ecological value alone. Grid proximity, construction feasibility, and permitting efficiency were consistently emphasized as key determinants. While wastelands may present fewer ecological and regulatory challenges, their development, like that of all land types, remains contingent on overlapping practical and policy considerations.

However, while the ecological suitability of various land types provides a foundation for biodiversity-friendly solar development, policy and permitting structures determine whether such practices are feasible. The next section explores the Finnish regulatory landscape and its influence on biodiversity outcomes.

6.2. Permitting and Policy Frameworks – Enablers or Obstacles?

Policy and permitting frameworks are central to the development of solar energy projects, particularly when ecological concerns must be balanced with rapid infrastructure deployment. In Finland, permitting for solar parks is currently handled in a decentralized and evolving manner. While the absence of rigid national-level barriers has allowed projects to move forward, developers and environmental experts identified several bottlenecks that hinder the integration of biodiversity considerations. This section draws on both the literature and interviews to evaluate how Finnish permitting structures enable or constrain ecological sustainability in solar energy development.

6.2.1. Inconsistencies Across ELY Centres

One of the most frequently mentioned challenges in the interviews was the inconsistent permitting decisions across Finland's regional Centres for Economic Development, Transport and the Environment (ELY Centres). These offices play a key role in determining whether nature assessments are required and in evaluating the environmental aspects of planned solar parks. However, interviewees (INT2, INT3, INT6) described notable differences in how these decisions are made. According to INT8, it is often attributed to differing local "cultures", such as a culture of conservation, bureaucracy, or leniency.

This variability affects project timelines and predictability. INT6 noted the difficulty in planning projects when "it would be desirable to know what kind of permitting timelines should be expected." Inconsistent application of permitting criteria not only delays projects but may also lead to uneven treatment of environmental risks across regions. As a result, developers often face uncertainty even when working with similar site types in different parts of the country.

6.2.2. Environmental Impact Assessment: Overrated or Underused?

Another recurring theme was the limited role of formal Environmental Impact Assessments (EIA) in solar park permitting. In Finland, solar energy projects under 200 hectares typically do not require an EIA, unless specific environmental concerns are raised. This threshold excludes most projects currently under development.

Interestingly, many interviewees did not view the lack of EIAs as a significant barrier to biodiversity protection. INT1, INT5, and INT8 pointed out that nature assessments are already carried out as part of the permitting process and are often of high quality. INT8 noted that "nature assessments at industrial-scale solar parks are conducted better than average…and reveal a genuine desire to consider nature."

However, the EIA process was also described as burdensome. It can take several years and involve multiple appeal rounds (INT3), making it a less attractive route for developers, even when potential ecological impacts might justify it. Some participants expressed concern that overly rigid EIA requirements could slow the adoption of solar energy without proportionate environmental benefits. Instead, they favored strengthening baseline permitting expectations rather than relying on the EIA framework for all projects.

6.2.3. Needed Reforms: Uniform Guidelines and One-Stop Licensing

Multiple interviewees suggested concrete reforms to improve the permitting process while maintaining environmental standards. A key recommendation was the development of clear, uniform national guidelines for ELY Centres. According to INT3 and INT8, harmonized expectations could reduce uncertainty and improve both the speed and ecological consistency of decision-making. INT8 proposed that if ELY Centres operated more uniformly and met minimum quality standards, it might even reduce the need for formal EIAs in many cases.

Another important reform is already underway. The permitting process is being restructured to fall under the construction license system, creating a "one-stop principle" that consolidates procedures (INT6). This change is expected to streamline timelines and improve coordination between permitting bodies. As INT6 remarked, "I see it as a good reform…it will likely standardize decisions."

Interviewees consistently raised concerns about fragmented and inconsistent permitting processes between ELY Centres. While there was no strong critique of ecological permitting itself, uncertainty about what each regional Centre might require was seen as a barrier to smooth project execution. Rather than opposing regulation, many developers expressed a desire for clear, predictable rules. As one interviewee noted, standardizing expectations could reduce the need for time-consuming assessments and appeals. This suggests that inconsistency does not necessarily prevent biodiversity measures, but it creates enough friction that such measures are unlikely to be prioritized unless already embedded in streamlined guidance.

Even with the right policies in place, the practical integration of biodiversity into industrial-scale solar parks ultimately depends on the actions of developers, local communities, and policymakers. The final section examines how these actors are addressing the challenges and where opportunities for improvement remain.

6.3. Driving Biodiversity in Solar Energy: Roles and Opportunities

Efforts to integrate biodiversity into industrial-scale solar park development are shaped not only by land type and project design, but also by the actors involved. Developers, policymakers, and communities each play a role in determining whether solar energy supports or undermines ecological resilience. While several practices are already in place, much of the ecological potential remains underutilized. This section examines what is currently being done and what more could be achieved by each group to better align solar energy expansion with biodiversity goals in Finland.

6.3.1. Developers: Current Practices and Design Opportunities

Interview findings revealed that many developers do consider ecological aspects during planning and construction, although the level of ambition varies between projects. Some avoid construction during bird nesting seasons or leave natural features like ponds and rocky outcrops untouched (INT3). In peatland projects, developers have used existing ditches instead of fences to allow wildlife movement while maintaining site security (INT4). In general, developers expressed openness to nature-enhancing measures as long as they do not interfere with safety or energy production.

While interviewees did not explicitly reference ecological theory, several proposed design strategies, such as habitat mosaics, vegetated corridors, and multifunctional land use, closely align with principles from landscape ecology. In particular, the emphasis on connectivity, edge conditions, and biodiversity-enhancing structures reflects an implicit understanding of how spatial design can support ecological functions across solar park landscapes (Fischer & Lindenmayer, 2007).

However, biodiversity measures are not yet a consistent part of project design. Several interviewees (e.g., INT3) highlighted that tight project budgets and the lack of regulatory requirements often lead to such actions being excluded. Deadwood, stormwater ponds, and floral strips were mentioned as valuable additions, but rarely implemented unless specifically requested by clients. This indicates that biodiversity remains an optional rather than embedded consideration in most industrial-scale solar parks.

There is also ecological potential in how vegetation is managed on site. Interviewees recommended using sheep grazing over mechanical mowing to maintain low-growing vegetation and support meadow habitats (INT3, INT6, INT8). Other suggestions included planting local flower species to benefit pollinators, especially where soils are already nutrient-poor (INT6, INT8). Such actions could be scaled up with minimal additional costs if considered early in the planning phase.

Construction is sometimes timed to avoid disruption during bird nesting and migration periods (INT3). This raises the question of whether project calendars should also take into account the breeding, hibernation, or migration periods of other fauna, such as amphibians or mammals. Expanding seasonal planning could further reduce ecological disturbance but would require more detailed ecological assessments at the site level and limit the construction schedule.

While many developers expressed a genuine interest in ecological integration, such as using grazing, native vegetation, or leaving buffer zones, these choices were framed as contingent on cost-efficiency and regulatory clarity. Without formal incentives or requirements, biodiversity remains a secondary concern, addressed when conditions allow but rarely built into project logic from the outset. This reflects a broader structural issue: biodiversity-supportive design is seen less as an integral part of solar planning, and more as a value-added feature, pursued only when external constraints (tight budgets, permitting complexity, or landowner preferences) don’t get in the way. Unless policies evolve to normalize these practices, they are unlikely to scale beyond a small group of motivated actors

6.3.2. Policymakers: Reform Needs and Incentive Structures

While the section 5.2 examined the broader permitting landscape and institutional inconsistencies, this subsection focuses on how specific policy decisions and regulatory tools shape developers’ ability to integrate biodiversity into solar park projects.

Although ecological assessments are typically conducted, there are currently no binding national requirements for biodiversity-supporting features. Several participants expressed support for introducing compensation requirements or minimum restoration standards. According to INT3, if some form of ecological compensation were required, “more things would be considered and done,” as these expectations would be built into early planning and budgeting. INT7 similarly noted that restoration efforts are often piecemeal and depend on voluntary initiative, due to the absence of policy obligations.

Inconsistent decision-making across ELY Centres further complicates this landscape. As discussed in Section 5.2, regional variation in permitting creates uncertainty for developers. Interviewees called for clearer national guidelines and minimum requirements to improve consistency and reduce reliance on full Environmental Impact Assessments. INT8 proposed that harmonised permitting standards could raise ecological quality while simplifying approval processes.

Views on financial incentives were mixed. Some interviewees supported subsidies to encourage biodiversity enhancements, while others expressed concern about the risk of greenwashing. INT8 argued that environmental actions should be integrated into companies’ Corporate Social Responsibility rather than funded externally. Funding should not be provided to corporations for measures that enhance biodiversity; instead, these measures should be automatically integrated into their operations. However, with the rise of large-scale industrial solar parks in Finland, it's essential to use incentives to encourage a behavioral shift that prioritizes biodiversity in project design from the beginning.

The upcoming transition to a one-stop licensing system under the new construction law was viewed as a promising reform. Several interviewees noted its potential to streamline procedures and improve clarity, especially if biodiversity expectations are embedded in the new framework.

In summary, while policy currently plays a limited role in supporting biodiversity in industrial-scale solar parks, there is broad agreement on the need for clearer guidance and stronger regulatory expectations. A shift toward standardized permitting, ecological compensation, and integrated biodiversity criteria could help align Finland’s solar energy goals with its environmental commitments.

6.3.3. Communities: Potential for Engagement and Co-Benefits

Community involvement in solar park development remains limited, but interviewees saw opportunities for improvement, particularly on agricultural or wasteland sites near residential areas. While fencing limits direct access to project areas, developers showed willingness to explore compatible dual uses. These included wildflower strips accessible from roadsides (INT3), planting boxes for local gardeners along fence lines (INT6), and partnerships with local seed suppliers or beekeepers (INT2, INT3).

Such arrangements may not generate profit but can improve public acceptance and increase the ecological value of solar parks. INT3 suggested that allowing low-impact community use could also foster shared stewardship and reduce opposition to future projects. However, interviewees also stressed that community engagement would require clear responsibilities, safety assurances, and compensation models to be feasible at scale (INT3, INT5, INT6).

In conclusion, while awareness of biodiversity issues is increasing among Finnish solar developers, current practices depend heavily on voluntary actions and local discretion. There is clear potential to improve outcomes through early integration of ecological planning, cost-effective design features, and grazing-based maintenance strategies. Policymakers can support this shift by harmonizing permitting criteria, exploring compensation frameworks, and ensuring ecological considerations are embedded in the evolving licensing system. Meanwhile, communities offer untapped potential for engagement and co-benefit creation, especially when projects are located near populated areas. Strengthening collaboration across these actors is essential if solar energy is to contribute not only to climate goals but to ecological restoration as well.

The discussion underscores the complexity of aligning industrial-scale solar development with ecological goals, particularly across varied land types and institutional settings. The table 2 provides a synthesized overview of the discussion section, focusing on the differences between theory and practice by contrasting insights from literature with findings from interviews. Building on these findings, the concluding chapter summarizes key insights and offers practical recommendations for policymakers, developers, and researchers.

Table 2. A synthesis of contrasting expectations from the theoretical literature and insights from interviews with stakeholders in the Finnish solar sector. The table highlights alignments, gaps, and conditional opportunities across key themes.

Theme	**Theoretical Insights (Literature)**	**Interview Findings (Practice)**
Peatland Solar	Opportunity for climate and biodiversity co-benefits via rewetting and restoration	Interest acknowledged, but actual projects remain rare due to permitting uncertainty and site complexity
Agricultural Fields	Ideal for dual-use; potential for biodiversity uplift	Most common land type used; biodiversity potential underutilized due to cost and practical concerns
Forests	Generally discouraged due to habitat fragmentation and carbon stock loss	Mostly avoided; some consider them acceptable if already degraded or economically marginal
Wastelands	Low ecological value; ideal for conflict free solar deployment	Regarded as easy to permit; interest limited by technical feasibility and location constraints
Biodiversity Strategies	Design measures (e.g., native plants, grazing) can support restoration and reduce maintenance.	Ecological practices applied inconsistently; adoption depends on individual motivation and incentives.
Permitting System	Needs to be clear, uniform, and enable ecological ambition	Inconsistencies across ELY Centres deter innovation; developers seek predictability over flexibility

Theme	Theoretical Insights (Literature)	Interview Findings (Practice)
Policy Support	Incentives and clear guidance are essential to scale nature-positive solar development	Largely absent; developers express the need for support to go beyond compliance
Community Engagement	Can enhance social license and deliver co-benefits, e.g., monitoring, grazing	Seen as valuable, but underutilized; often informal or ad hoc

7. Conclusion

This thesis explored how biodiversity and ecological restoration can be integrated into the development of industrial-scale solar parks in Finland. Drawing on a theoretical framework and qualitative interviews with solar developers and environmental experts, the study addressed the ecological effects of solar development across different land types, the enabling and constraining aspects of Finnish policy and permitting systems, and the roles that various stakeholders can play in advancing biodiversity-positive solar energy.

The first research question asked how industrial-scale solar parks in Finland affect biodiversity across different land types, and which design features can mitigate these impacts. The findings show that the ecological impact of solar parks is highly dependent on land type. Forested areas, while sometimes considered for development, are particularly unsuitable due to their ecological complexity and role in carbon storage. Conversely, degraded peatlands and underutilized agricultural fields present opportunities for synergy between energy production and ecological recovery. When combined with practices such as sphagnum moss transplantation, adaptive water management, native vegetation seeding, and managed grazing, solar parks on these lands can enhance biodiversity while also contributing to climate mitigation.

The second research question examined how Finnish permitting and policy frameworks enable or constrain biodiversity considerations in solar energy projects. The study found that the regulatory landscape is currently fragmented and inconsistent. Environmental assessments are determined on a case-by-case basis by regional ELY Centres, leading to wide variability in ecological requirements. Many projects avoid Environmental Impact Assessments altogether due to size thresholds. While some developers are proactive in assessing environmental risks, the lack of standardized national guidelines, ecological compensation mechanisms, and targeted financial incentives restricts the systematic incorporation of biodiversity concerns across the sector.

The third research question asked what actions are being taken, or could be taken, by developers, policymakers, and communities to integrate nature considerations into solar park development in Finland. While some developers are already experimenting with pollinator habitats, sheep grazing, or native plantings, more could be done to support diverse species within solar parks. One promising strategy is the intentional creation of varied microhabitats within project areas, such as compiling rock piles, leaving deadwood, and constructing ponds or shallow wetlands. These features attract a range of species, including insects, birds, amphibians, and reptiles, thereby enhancing the site's overall ecological value. Such structural elements contribute to a mosaic of environments within the solar park, improving habitat complexity and supporting biodiversity throughout the project’s lifecycle.

However, most of these biodiversity-enhancing actions remain voluntary and often rely on developer interest or sustainability values. Greater support from policymakers through clearer permitting standards, ecological design guidelines, and financial incentives, could help mainstream these practices. Similarly, there is potential for community involvement through low-impact uses such as wildflower harvesting, bee farming, or local planting initiatives, although current fencing and safety constraints limit access. With greater coordination and vision, solar parks could evolve into multifunctional spaces that contribute to both renewable energy goals and ecological resilience.

In conclusion, the transition to solar energy in Finland presents noteworthy potential to align with biodiversity objectives; however, this necessitates careful consideration of land-use decisions, ecologically informed design, and the establishment of supportive policy frameworks. If solar parks are located on degraded lands and designed with habitat diversity in mind, there is the possibility that they could serve as catalysts for climate mitigation as well as contribute to ecosystem recovery and local engagement. Nonetheless, these outcomes should be approached with caution, as the effectiveness of such initiatives will depend on the specific contexts and implementation strategies employed..

7.1. Limitations of the Thesis

While this thesis offers insights into the integration of biodiversity considerations into industrial-scale solar energy development in Finland, several limitations should be acknowledged. First, the rapidly evolving nature of Finland's renewable energy sector means that regulatory frameworks, market dynamics, and technological solutions are in flux. As a result, some policy insights may become outdated quickly. Second, due to the novelty of large-scale solar development in Finland, most current projects are still in early stages. Consequently, empirical evidence on long-term ecological impacts or restoration outcomes is limited, and much of the analysis relies on anticipated rather than observed effects. Finally, while interviews with developers and experts provided rich qualitative data, the perspectives of other stakeholders, such as local communities, conservation NGOs, and agricultural actors, were not systematically included and may reveal additional concerns or opportunities for biodiversity integration.

7.2. Recommendations for Public Authorities and Policymakers

To support biodiversity-conscious solar development, several key actions are recommended for public authorities and policymakers. Permitting procedures across Finland's regional ELY Centres should be standardized to ensure consistent and transparent decision-making that accounts for ecological impacts. This would help reduce uncertainty for developers while reinforcing national biodiversity goals. In parallel, targeted incentives or support mechanisms, such as grants, subsidies, or ecological compensation schemes, should be introduced to encourage the integration of restoration and biodiversity-enhancing features into industrial-scale solar park design. Additionally, land-use and subsidy frameworks should be reformed to accommodate multifunctional land management strategies, including agrivoltaics. These dual-use approaches would allow solar parks to coexist with agriculture, reduce land-use conflicts, and promote ecologically and socially beneficial outcomes.

7.3. For Further Research

Several areas also warrant further research. Long-term biodiversity monitoring is needed to evaluate the actual ecological impacts of solar parks over time and across different land types. Species-specific studies, particularly on reptiles, amphibians, and bird populations, could help refine mitigation measures and design strategies. In addition, more comparative research is needed on restoration techniques for peatlands and on the effectiveness of passive versus active recovery methods. Emerging opportunities such as agrivoltaics and community-integrated solar parks should be studied through pilot projects to better understand their feasibility, co-benefits, and public reception. Lastly, low-vegetation marginal areas, like roadsides, highway verges, and utility corridors beneath power lines, offer untapped potential for ecologically sound solar installations and deserve greater attention in both research and policy.

In closing, this thesis contributes to the emerging field of nature-positive energy transitions. It offers actionable insights for developers, planners, and public authorities and highlights the importance of treating biodiversity not as an afterthought but as a co-equal priority in renewable energy development.

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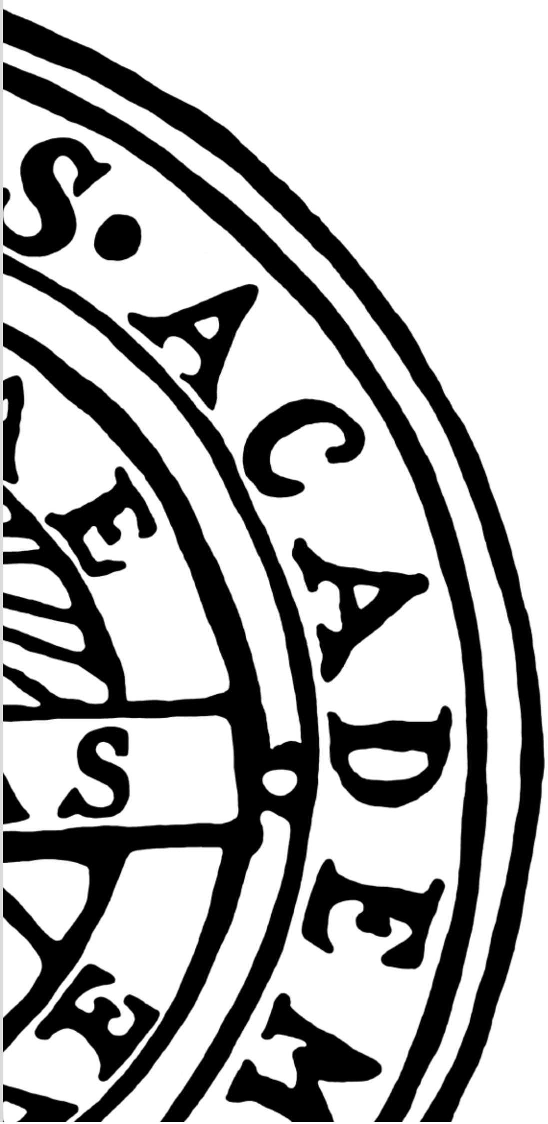
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