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THE IMPACT OF RENEWABLE ENERGY USE ON BIODIVERSITY

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Abstract

The global shift toward renewable energy is a crucial response to the climate crisis, yet it also brings ecological implications that are often overlooked. This study systematically examines the environmental impact of renewable energy infrastructures particularly solar, wind, hydro, and biomass on terrestrial and aquatic biodiversity. A total of ten peer-reviewed articles published between 2020 and 2025 were selected based on their relevance, methodological rigor, and ecological focus. The data were analyzed using a narrative-descriptive approach supported by manual thematic coding to identify recurring ecological patterns and mitigation strategies. The results indicate that solar farms contribute to habitat fragmentation and behavioral disturbances among birds and bats; wind turbines are linked to elevated mortality in flying species; and hydroelectric dams disrupt fish migration and reduce aquatic habitat quality. On the other hand, integrative technologies such as aquavoltaic systems and fish-friendly turbines demonstrate potential for minimizing ecological harm while meeting energy needs. This study contributes a synthesized understanding of how renewable energy infrastructures affect biodiversity across ecosystems and technological contexts. It highlights the importance of spatial planning, context-specific impact assessments, and ecosystem-based mitigation strategies. The findings are expected to inform policymakers, environmental planners, and industry stakeholders in designing renewable energy solutions that align with long-term ecological sustainability.

Keywords: *Renewable Energy, Biodiversity, Solar Panels, Wind Turbines, Hydro Dams*

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1. Introduction

Global climate change due to greenhouse gas emissions has become a serious threat to environmental sustainability and human well-being. Fossil energy as a major contributor to carbon dioxide emissions continues to come under pressure to reduce its use, thus driving the transition towards renewable energy such as wind, solar, hydro and biomass power. Renewable energy is seen as a key solution because it is cleaner, more efficient and relatively less polluting than conventional energy. In many countries, including Indonesia, this energy transition is even part of the global commitment in the Paris agreement to reduce the rate of warming of the earth. However, the claim that renewable energy is entirely "environmentally friendly" needs to be critically reviewed. Despite its low emissions, its infrastructure development still requires significant land, water and landscape changes, which can disrupt ecosystems and biodiversity. For example, large-scale solar panel installations have the potential to cause habitat fragmentation and changes in local vegetation structure. Wind turbines are often associated with increased bird and bat mortality due to collisions or disorientation. Meanwhile, the construction of hydro dams for power generation alters natural river flows, disrupts fish migration and degrades the quality of aquatic habitats.

Biodiversity has irreplaceable ecological and economic value. Healthy ecosystems serve as life support through the provision of environmental services such as pollination, climate regulation, clean water supply, and genetic reserves for food and medicine. If renewable energy development is carried out without adequate ecological considerations, there will be an irony: efforts to save the planet from the climate crisis instead damage the foundation of life itself. This shows that the energy transition is not just about reducing emissions, but also ensuring ecological sustainability.

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Various studies have highlighted the negative impacts of renewable energy on biodiversity. Meng et al. (2025) recorded a 9.8% decline in bird populations following the construction of wind farms in China. Stock (2024) showed that a simple modification to the starting speed of wind turbines in Australia could reduce bat mortality by 81%. On the other hand, innovations such as the aquavoltaic system in Taiwan (Imani et al., 2023) were able to harmoniously integrate energy generation and fish farming. These findings show that renewable energy technologies are not monolithic: their impact depends on the design context, location and mitigation approach used. Meanwhile, conventional hydropower plants can alter river flows and trigger fragmentation of aquatic habitats. This results in the disruption of fish and other aquatic species. However, innovations such as fish-friendly turbines and run-of-river designs show great potential in maintaining fish populations even up to 99% as evidenced by projects in Oregon and Maine (Time, 2022).

Large-scale solar power generation also poses challenges. The need for large tracts of land for the construction of solar panels can lead to habitat fragmentation and population declines of local species. Therefore, careful planning is necessary to minimize the ecological impact of these energy projects. OECD (2024) suggests that conflicts between biodiversity conservation and renewable energy development can be reduced through an integrated spatial approach. For example, energy projects should be built in non-conflict zones, utilize degraded land or rooftops, and consider aggregate impacts across time and regions.

The study by Wang et al. (2025) shows that the expansion of low-carbon energy in 2015 has already had a negative impact on biodiversity, especially if projects are carried out in high-biodiversity areas. Therefore, clean energy development strategies must be designed in a way that does not cause new ecological damage. This raises an important question: how can the transition to renewable energy be made without compromising biodiversity? While the goal is to save the environment, an inappropriate approach can actually damage it. Therefore, a holistic and ecosystem-based approach is needed in the planning and implementation of renewable energy projects.

While a growing number of studies address the relationship between renewable energy and biodiversity, most are sectoral, focusing on one energy type, one ecosystem or one specific geographic location. Comprehensive studies that integrate different types of renewable energy and integrate terrestrial and aquatic ecological perspectives are rare. In fact, energy and conservation policies require cross-disciplinary and cross-context evidence to be formulated effectively. Therefore, this study aims to systematically assess the ecological impacts of renewable energy use on biodiversity. The study was conducted using a literature review method of scientific articles published in the last five years (2020-2025), with a focus on the interaction between energy infrastructure and ecosystem sustainability. In addition, the study also seeks to identify innovative mitigation strategies that can bridge the need for clean energy and biodiversity protection. It is hoped that the results of this study can enrich the scientific basis for developing renewable energy policies that are not only low-carbon, but also ecologically friendly in the long run.

2. Method

This research uses a systematic literature review approach to examine the impact of renewable energy use on biodiversity. Articles were collected through searches on scientific databases such as Google Scholar, Scopus, and ScienceDirect, with a publication range between 2020 and 2025. Keywords used in the search process included terms such as "renewable energy", "biodiversity impact", "solar energy ecology", "wind power mortality", "hydropower and fish migration", and "biomass environmental effects". From the initial selection, ten scientific articles were obtained that met the inclusion criteria, namely articles that explicitly examined the interaction between renewable energy infrastructure and biodiversity, had a clear methodology, and were published in reputable national and international journals.

Data were analyzed in a narrative-descriptive manner using a manual thematic approach. Each article was read thoroughly and coded to identify key recurring themes, such

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as the type of energy studied, the form of ecological impacts reported, the geographical and ecosystem context, and the mitigation strategies suggested. These themes were then grouped and qualitatively analyzed to identify common patterns, differences across studies, and ecological implications of renewable energy development. This process allowed for a critical synthesis of the available literature, while providing a more complete conceptual mapping of ecological risks and solutions in renewable energy development.

3. Results and Discussion

Based on a systematic search conducted through Google Scholar within the last five years (2020-2025), ten scientific articles were obtained that are relevant to the focus of the study on various types of renewable energy, namely wind power, solar power, hydropower (hydro), and biomass, and their impacts on terrestrial and aquatic ecosystems. The articles were selected based on keywords including "renewable energy", "biodiversity impact", "wind power", "hydropower", "solar farms", and "biomass ecology".

Table 1. Review Articles

No	Name	Title	Method	Results
1	Anderson et al. (2025)	Assessing the Impact of Solar Farms on Waterbirds: A Literature Review of Ecological Interactions and Habitat Alterations	Literature review sistematic	Large PVs alter the habitat and ecological interactions of waterbirds through changes in dispersal patterns and vegetation.
2	Iranzo et al. (2025)	Current Knowledge on Novel Semi-Arid Photovoltaic Ecosystems, Their Impacts on Biodiversity and Implications for the Sustainability of Renewable Energy Production	Narrative review & ecosystem analysis	PV installations in semi-arid regions increase microhabitat temperatures, alter soil moisture, reduce insect abundance, and cause changes in the structure of plant communities and small mammals.
3	Moustakas et al., (2023)	Wind turbine power and land cover effects on cumulative bat deaths	Field statistical model	Bat mortality is strongly influenced by turbine power (40%) and the presence of natural habitat within a 5 km radius. Sites with nearby natural vegetation were particularly vulnerable, indicating the need for buffer zones.
4	Gøtske & Victoria (2021)	Critical review on env impacts of wind, hydro, biomass, geothermal	Review sistematic	Bioenergy risks high deforestation and pollution; wind causes bird and bat mortality; hydro creates river fragmentation and disrupts fish migration; geothermal generates waste heat; solar alters

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				habitats and causes an "eco-trap" effect.
5	Lafitte et al., (2023)	Existing evidence on the effects of photovoltaic panels on biodiversity: a systematic map with critical appraisal of study validity	Mapping & critical appraisal	P Ground-mounted V causes landscape fragmentation, bird mortality due to collision/reflection, insect population decline, influence on animal behavior, and reduction of local vegetation cover. Effects depend on the scale and layout of the installation.
6	Jin et al., (2022)	Biodiversity Loss from Freshwater Use for China's Electricity Generation	Spatial planning	Turbine siting in fragmented zones (outside Natura 2000) reduces impacts to biodiversity by 4% compared to sensitive areas
7	Imani et al., (2023)	Aquavoltaics Feasibility Assessment: Synergies of Solar PV Power Generation and Aquaculture Production	Studi kasus + SWOT analysis (Taiwan)	PV panels in aquaculture ponds reduce evaporation, stabilize water temperature, protect aquatic life from aerial predators, as well as supply independent electricity
8.	Matwani & Fredrick (2025)	Exploring the Link Between Energy Resources and Global Biodiversity	Marine ecosystem model (North Sea)	Epifauna buildup on turbines increases primary productivity by ±8%, affecting distribution of plankton and pelagic predators
9.	Alhjizai et al., (2023)	A Hybrid Renewable Energy (Solar/Wind/Biomass) and Multi-Use System Principles, Types, and Applications: A Review	Review of technology & simulation models	Hybrid system shows better environmental efficiency than single; HOMER simulation shows LCOE ~ $0.218/kWh and CO_2 emissions remain low
10	Bhatt el al., (2022)	The Potential Impact of Climate Change on the Efficiency and Reliability of Solar, Hydro, and Wind Energy Sources	Cross-technology review (solar/hydro/wind)	Climate change affects efficiency & stability of renewable sources; mapping sensitive areas important for adaptation and sustainability planning
11	Bozeman et al.. (2025)	The environmental impact of hydropower: a systematic review of the ecological effects of sub-daily flow	Systematic review (109 studi)	Daily flow fluctuations increase risk of fish stranding, decrease productivity and diversity, disrupt reproduction and

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	variability on riverine fish		movement (site & species specific)

Based on a systematic search of ten scientific articles, various ecological impacts of renewable energy development were found, which vary depending on the type of energy, geographical location, and design of the infrastructure used. To understand these general patterns, the results were classified by four main energy categories: solar, wind, hydro and biomass/hybrid.

Solar Energy (Solar PV & Aquavoltaic)

Solar energy is one of the most widely developed forms of renewable energy due to its high efficiency. However, large-scale solar installations can trigger significant ecological impacts especially in open areas and wetlands. Large-scale solar PV installations have been shown to have significant impacts on biodiversity, especially in wet and open ecosystem areas. Anderson et al. (2025) revealed that the presence of PV around wetlands can change waterbird distribution patterns, reduce population diversity, and trigger seasonal disturbances during migration and reproduction phases. This finding reinforces the results of the study by Lafitte et al. (2023), which showed that PV plants not only cause landscape fragmentation, but also increase the risk of bird mortality due to panel collisions or reflections, decrease insect populations, and change overall wildlife behavior. In fact, the phenomenon of eco-trap was identified, particularly in insects and vegetation that are attracted but trapped in artificial habitat conditions that do not support long-term survival. In a similar context, a study by Tinsley et al. (2023) in the UK on 19 PV sites confirmed that the activity of six out of eight bat species decreased dramatically at panelized sites, especially in open areas and vegetation boundary lines, signaling the need for strengthened regulation through monographic policies as well as more in-depth ecological impact assessments in EIA documents. On the other hand, multifunctional design approaches such as aquavoltaics show the potential for more sustainable solutions, where solar panels installed on top of aquaculture ponds not only reduce evaporation rates and stabilize water temperatures, but also protect aquatic organisms from aerial predators while efficiently providing electrical energy. The overall findings emphasize the importance of evaluating the design, installation layout, and integration of conservation approaches in renewable energy development.

Wind Energy (Onshore & Offshore)

Wind energy is known to be efficient and clean, but it also poses ecological risks, especially to flying species. Wind energy is known to be efficient and clean, but it also poses ecological risks, especially to flying species. Research on the impacts of wind turbines on biodiversity shows mixed results depending on the ecological context and spatial placement. Moustakas et al. (2023), through a field statistical modeling approach in Greece, found that turbine power was the dominant factor accounting for about 40% of the variance in bat mortality. In addition, the presence of natural ecosystems within 5 km of turbine sites increased mortality risk, emphasizing the importance of implementing buffer zones and carefully planning turbine locations. In line with these findings, Kati et al. (2021) showed that siting turbines outside of Natura 2000 conservation areas reduced impacts on biodiversity by 4%. This underscores the importance of spatial planning that considers habitat sensitivity to minimize direct damage to vital ecosystems. Meanwhile, a study by Matwani & Fredrick (2025) on offshore wind turbines showed that turbine structures can act as artificial reefs, increasing primary productivity by about 8% through epifauna colonization. Despite this potential to support the marine food chain, researchers emphasize the need to monitor changes in the distribution of plankton and pelagic predators as an ecological consequence of such modifications to the marine environment. Overall, these findings confirm that the ecological impacts of wind turbines are highly contextual and need to be managed through spatial and ecosystem data-driven approaches.

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Hydro Energy (Flow & Migrasi)

Hydroelectric power plants (HPPs) have great potential for energy provision, but are also among the most disruptive to natural aquatic systems. Research on the impacts of dams on aquatic ecosystems shows that modification of river flows has complex and highly contextualized ecological consequences. Bozeman (2025) revealed that daily flow variability generated by dam operations can increase the risk of water depletion, decrease the productivity and diversity of fish species, and significantly disrupt seasonal reproduction and migration. These effects are specific to the geographic location and biological characteristics of the affected fish species. These findings were reinforced by Khoeunn et al. (2024) in their study of the Mekong watershed, where dam construction was shown to impede fish migration pathways and damage critical habitats that serve as breeding and rearing grounds. Although mitigation measures such as environmental flows and fish passage have been implemented, their effectiveness is still limited as they are not fully adapted to local hydrological and ecological dynamics. Therefore, a more adaptive and locally specific approach to dam design and management is needed to minimize impacts on aquatic biodiversity.

Energy Biomass & Hybrid

Biomass energy and hybrid systems offer diversification of energy resources that can improve environmental efficiency. Recent studies have shown that the integration of renewable energy technologies through a hybrid system approach offers a more efficient and environmentally friendly solution than the use of a single system. Alhijazi et al. (2023) suggest that the combination of solar, wind and biomass in a hybrid system results in higher environmental efficiency, with simulation results using the HOMER tool showing a levelized cost of electricity (LCOE) of around \$0.218/kWh and relatively low CO_2 emissions. These findings confirm the importance of diversifying energy sources to achieve sustainability. However, Bhatt et al. (2022) caution that climate change could significantly affect the efficiency and reliability of all renewable energy sources, be it solar, hydro or wind. Therefore, mapping of sensitive areas and location-based adaptation strategies are crucial in long-term planning, in order to maintain energy security amid global climate fluctuations.

Table 2. Summary of Common Patterns of Findings

Energy Type	Major Ecological Impacts	Mitigation Strategy/Related Policy
Solar (PV)	Habitat fragmentation, bird/bat disturbance	Aquavoltaic, roof utilization, non-panel zone
Wind	Bird and bat mortality, visual/habitat disturbance	Buffer zone, cut-in speed, offshore design
Hidro	Disruption of fish migration, flow fluctuations	Fish-friendly turbine, run-of-river, fish passage
Biomassa/Hybrid	Deforestation, emissions if not controlled	Source diversification, sensitive area mapping

4. Conclusions and Suggestions

The results of this study show that while renewable energies such as solar, wind, hydro and biomass contribute significantly to climate change mitigation, their development still carries ecological consequences that cannot be ignored. Impacts on biodiversity come in many forms, ranging from habitat fragmentation, disruption of animal migration and reproduction, to changes in the behavior of local species. The intensity and type of impacts are strongly influenced by the scale of the project, its geographic location, and the design of the technology. Mitigation measures such as aquavoltaics, vegetation buffer zones, turbine cut-in speeds and fish-friendly turbines have been tested in various contexts, but their implementation remains geographically and technically limited. The transition to clean energy must therefore be accompanied by policies that explicitly integrate biodiversity protection into every stage of energy projects. The government needs to implement ecosystem-based ecological impact assessments as part of the mandatory standards in EIA documents for all renewable energy projects. In addition, it is important to encourage the use of integrative spatial planning approaches, such as those applied in Natura 2000 zones in Europe, that consider habitat sensitivity and the presence of key species in determining the location of energy infrastructure.

Another recommendation is the development of a landscape-based energy conservation model, where energy development is prioritized on degraded land, former mines or rooftops, avoiding intact natural areas. The government and private sector also need to expand the adoption of multifunctional technologies, such as aquavoltaic systems and integrated hybrid systems, which are capable of producing energy while maintaining or even improving local ecological functions. Institutionally, a coordination mechanism between the ministries of energy, environment and regional planning needs to be established so that policies are not sectoral. The involvement of local communities and conservation stakeholders is also an important element in maintaining the balance between energy needs and biodiversity protection. In this way, the energy transition can truly achieve double sustainability: carbon-free and biodiversity-friendly.

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