

Review

Biodiversity and renewable energy in a warming world: Pathway to mitigate climate change while preserving ecosystem

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Abstract: This review examines the dual roles of renewable energy in mitigating climate change and preserving biodiversity. It looks at the direct and indirect impacts of renewable energy on biodiversity and highlights strategies for striking a balance between energy development and ecological conservation. The global climate crisis demands immediate action, and renewable energy is a key component of efforts to mitigate climate change. However, while renewable energy technologies like solar, wind, and bioenergy hold significant potential to reduce greenhouse gas emissions, their deployment also presents risks to biodiversity. The relationship between renewable energy and biodiversity conservation is complex, as energy infrastructure can cause habitat destruction, ecosystem disruptions, and habitat fragmentation, potentially aggravating the very environmental challenges that renewable energy seeks to address. Whereas renewable energy technologies can lessen the environmental impact of human activity, their widespread use may have unforeseen effects on species and ecosystems. If not properly managed, renewable energy projects have the potential to cause major changes in land use, including desertification, deforestation, and the disruption of delicate ecosystems. Ecosystems may also be harmed by the exploitation of raw resources for renewable energy, such as lithium for batteries and rare earth elements for wind turbines. This review examines the main obstacles to coordinating the growth of renewable energy with the preservation of biodiversity, including the effects of wind farms on bat and bird populations, the way hydropower dams change river ecosystems, and the possibility that bioenergy crops would supplant native flora. It then suggests ways to lessen these effects, such as improved site design, more effective energy systems, and incorporating biodiversity concerns into legislative frameworks. In order to guarantee that renewable energy contributes to a sustainable future for both climate and biodiversity, the study concludes by highlighting the necessity of a multidisciplinary strategy that combines energy and conservation policy.

Keywords: biodiversity; renewable energy; climate change; ecosystem

1. Introduction

Rising temperatures, more intense weather, and changing ecological patterns are all signs of the growing climate problem, which has emerged as one of the 21st century's most significant issues. Carbon dioxide concentrations in the atmosphere have reached previously unheard-of levels due to human activity, specifically the burning of fossil fuels, deforestation, and industrial operations [1]. The richness of life on Earth, or biodiversity, has been declining at startling rates at the same time, with species extinction happening 1000–10,000 times faster than the natural background rate [2]. These two crises are not only related but also reinforce one another since biodiversity loss is made worse by climate change, and ecosystems

become less resilient to the effects of climate change when biodiversity declines. Changes in species distributions, altered habitats, and a rise in invasive species and diseases are some of the ways that climate change impacts biodiversity. Warming temperatures force species over their physiological limitations, resulting in population decreases and extinctions, while rising sea levels endanger coastal habitats [3]. Often referred to as the “rainforests of the sea”, coral reefs are one of the ecosystems most at risk from climate change. The livelihoods of millions of people who rely on these ecosystems are in danger due to widespread coral bleaching and mortality brought on by ocean acidification and thermal stress brought on by rising carbon dioxide levels [4]. On the other hand, biodiversity is essential for reducing the effects of climate change. Mangroves, marshes, and forests all serve as organic carbon sinks, removing enormous volumes of carbon dioxide from the atmosphere [2].

However, there are environmental consequences associated with the expansion of renewable energy infrastructure. Large-scale solar farms frequently necessitate a large amount of land, which causes species displacement and habitat fragmentation. Despite being an essential part of clean energy, wind turbines can endanger bat and bird populations, especially if they are situated along migratory routes [5]. By changing fish migration patterns, sediment transport, and water flow, hydropower dams disturb river ecosystems [6]. Food security issues may worsen if bioenergy plantations are not managed properly since they may cause deforestation and compete with food crops [7]. These compromises highlight how crucial it is to incorporate biodiversity concerns into the design and application of renewable energy. Adopted in 2015, the Paris Agreement highlights the need for equitable and effective climate action [8]. This entails acknowledging how climate and biodiversity goals are interdependent and making sure that actions taken to slow down climate change don't harm ecosystems. For example, carefully placing renewable energy plants in low-biodiversity or degraded areas might maximize climatic benefits while minimizing ecological consequences [9]. Technological innovations like bio-inspired wind turbine designs and floating solar farms provide creative ways to lessen the environmental impact of renewable energy systems [10,11].

Significant gaps still exist in converting policy pledges into practical tactics on the ground, notwithstanding these efforts. Governments, businesses, researchers, and communities must work together to close these gaps and create comprehensive strategies that strike a balance between biodiversity and climate goals. Additionally, renewable energy may help alleviate economic and social disparities. Off-grid solar solutions and other decentralized renewable energy systems can supply electricity to isolated and underprivileged areas, enhancing their standard of living and promoting economic growth. Residents are empowered by community-owned renewable energy projects, which guarantee that the advantages of clean energy are shared fairly [12]. Similar to this, incorporating green infrastructure into renewable energy projects—like wildlife corridors and vegetated buffers—can lessen ecological effects and promote ecosystem functioning [13]. Although there are many obstacles to overcome, coordinating the growth of renewable energy with the preservation of biodiversity is not impossible. Climate and biodiversity goals can be harmoniously

balanced by using a system-based approach that takes ecological, social, and economic factors into account. In order to provide a path for a transition to renewable energy that is sensitive to biodiversity, this review attempts to clarify these potential and obstacles. We examine how renewable energy might help mitigate climate change, how renewable energy technologies affect biodiversity, and how to match the use of renewable energy with conservation objectives in the parts that follow. This paper aims to contribute to the current discussion on sustainable development in a warming world by providing a thorough synthesis of the body of existing material.

2. Literature review

The body of research on the connection between renewable energy and biodiversity is extensive and identifies both potential and problems. Research continuously demonstrates that habitat loss, species migration, and changed ecosystem dynamics are just a few of the direct and indirect impacts of climate change on biodiversity. When not properly designed, renewable energy might unintentionally lead to habitat fragmentation and ecological disruption even when it is reducing the effects of climate change [14,15]. Another major topic has been the interaction between offshore wind farms and marine species. Bailey et al. [14] shed light on these installations' dual function as possible marine ecosystem disruptors and enhancers [7]. Technological innovations like floating solar panels and bird-safe wind turbines are examples of continuous attempts to balance the development of renewable energy with the preservation of biodiversity [16,17]. Another crucial area of research is governance systems and policy frameworks. The goal of the EU's Renewable Energy Directive and related regulations is to strike a balance between environmental preservation and energy expansion [11]. Furthermore, the necessity of worldwide initiatives to incorporate biodiversity into energy planning is highlighted by international partnerships like the Convention on Biological Diversity (CBD) [18].

2.1. The Implications and interactions of climate change on biodiversity

One of the biggest risks to biodiversity is climate change. Ecosystems are disrupted by rising temperatures, changing precipitation patterns, and an increase in the frequency of extreme weather events, which force species to migrate or adapt (**Figure 1**). But not all species can adapt to the changing environment or relocate fast enough [19]. Certain ecosystems, including wetlands and coral reefs, are especially susceptible to even minor changes in weather and temperature, which can result in the extinction of species and the loss of ecosystem services [20]. Overuse of natural resources and habitat destruction exacerbate the detrimental effects of climate change on biodiversity. Human-induced ecosystem change is hastening the loss of biodiversity (**Figure 1**), which has significant ramifications for ecosystem resilience [21]. To prevent one catastrophe from exacerbating the other, it is imperative that the climate crisis and biodiversity loss be addressed together.

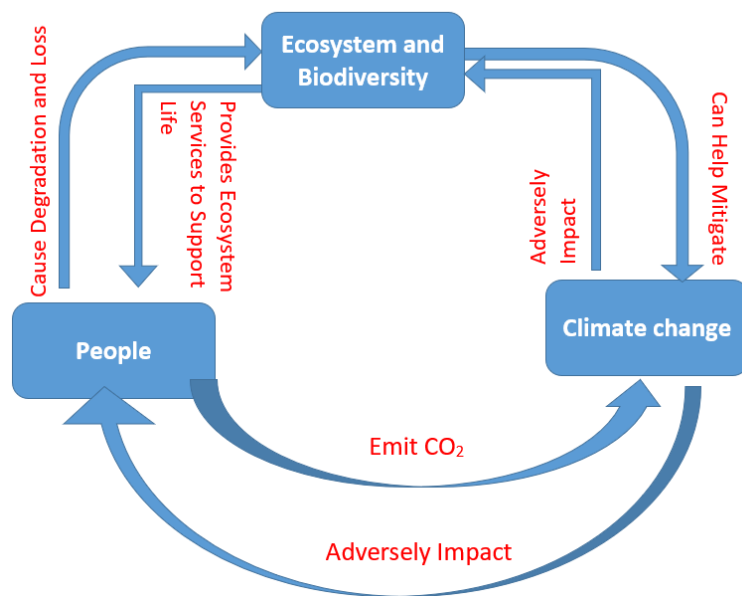


Figure 1. Ecosystem-based adaptation and climate change mitigation.

2.2. The function of renewable energy technologies in climate mitigation

Renewable energy technologies are critical to mitigating the effects of climate change. The following sections discuss the environmental benefits and challenges of each renewable energy source.

Bioenergy production often involves land-use changes, such as converting forests into plantations, which can lead to biodiversity loss [7]. Monoculture plantations, commonly used for bioenergy crops, provide limited habitat value compared to natural ecosystems. Sustainable practices, such as integrating agroforestry, can mitigate these impacts while maintaining carbon sequestration benefits [22]. Bioenergy systems also offer opportunities for waste utilization. For example, agricultural and forestry residues can be used as feedstock for bioenergy production, reducing the need for additional land conversion. Advances in bioenergy technologies, such as cellulosic ethanol and algae-based biofuels, hold promises for enhancing sustainability and reducing ecological impacts. Wind Power: With the quantity and capacity of wind farms growing quickly, wind energy plays a significant role in the world's renewable energy supply. However, local species, particularly birds and bats, which are susceptible to accidents, may suffer because of wind turbines [23]. Additionally, wind farm construction can disturb migratory pathways and fragment habitats [24]. These effects can be lessened by innovations in turbine design, such as offshore wind farms and smaller, quieter models [6].

Solar energy is one of the most promising renewable energy sources. Concentrated solar power (CSP) plants and photovoltaic (PV) cells have seen significant improvements in scale and efficiency [25]. Solar power helps decarbonize energy systems and reduces dependency on fossil fuels, but large-scale solar projects can require a lot of land, which could potentially displace sensitive ecosystems [26]. For instance, in desert ecosystems, large-scale solar installations may disturb delicate

plant and animal communities. These effects (**Table 1**) can be lessened with careful planning and land selection [27].

Table 1. Ecological impacts of solar energy development: Habitat loss, species displacement, and mitigation strategies.

Impact	Description	Mitigation Strategy
Habitat Loss	Conversion of land for solar farms	Site Selection to avoid ecologically sensitive areas, use of degraded land
Species displacement	Loss of species due to habitat disruption	Integration of biodiversity corridors, use of native plant species
Soil degradation	Soil erosion due to land conversion	soil conservation practices, such as erosion control measures

Hydropower, for many years, has been regarded as a dependable renewable energy source. However, massive hydropower projects, like dams, have the potential to drastically change river ecosystems by obstructing fish movement and inundating vast tracts of land [28]. Furthermore, aquatic species and the nearby terrestrial habitats may be impacted by the disturbance of river flows [28]. These effects could be reduced by modifying existing structures or implementing small-scale hydropower projects [6]. For instance, the Noor Ouarzazate Solar Complex in Morocco, one of the world's largest concentrated solar power plants, has significantly reduced the country's carbon footprint. By generating over 580 MW of clean energy, it prevents approximately 760,000 tons of CO₂ emissions annually. This transition to solar power has reduced dependence on fossil fuels, mitigating climate change and protecting biodiversity in desert ecosystems by limiting habitat destruction from mining and fossil fuel extraction [29]. Also, it was reported that Denmark's investment in offshore wind energy has made it a global leader in renewable energy. The Horns Rev wind farms supply a significant portion of the country's electricity while reducing carbon emissions by millions of tons annually. This shift to wind power has not only helped mitigate climate change but also preserved biodiversity by reducing air and water pollution, benefiting marine and terrestrial ecosystems [30].

2.3. Impacts of renewable energy development on the environment

Despite being cleaner than fossil fuels, renewable energy sources nevertheless have a big influence on the environment (**Table 1**). The main issues are as follows:

Habitat destruction and land-use change: The construction of big renewable energy infrastructure, including hydropower dams, solar fields, and wind farms, necessitates a significant amount of land, which could result in habitat fragmentation and destruction (**Table 1**) [27]. For instance, solar farms have the potential to upset delicate plant and animal communities that have adapted to dry environments in desert ecosystems [26].

Resource extraction and biodiversity loss: Metals and rare earth elements must be extracted in order to produce renewable energy technologies. Both terrestrial and aquatic ecosystems may suffer because of habitat damage and environmental degradation brought on by mining for these resources (**Table 1**) [31]. Ecosystems may be harmed by the extraction of lithium and cobalt for batteries used in solar panels and electric cars [32].

Ecosystem service disruption: Hydropower dams and other renewable energy infrastructure can disrupt ecosystem services like nutrient cycling, flood control, and water filtration. Human populations and wildlife may suffer as a result of these disturbances [6].

2.4. Strategies to mitigate renewable energy impacts on biodiversity

To lessen the negative effects of the growth of renewable energy on the environment, several tactics can be used:

Environmentally aware positioning, renewable energy projects should be carefully planned and located to avoid areas of high biodiversity value, migratory corridors, and crucial habitats. Early in the planning process, environmental impact assessments (EIAs) can help direct decision-making and guarantee that possible threats to ecosystems are recognized and reduced [33].

Combining renewable energy with conservation objectives, it is crucial to implement policies that combine biodiversity preservation with renewable energy. For instance, sustainability standards in the European Union's Renewable Energy Directive make sure that renewable energy projects don't negatively impact biodiversity [34]. To guarantee ecologically sustainable development, national energy policy should also take biodiversity into account [7].

New technologies and new developments in renewable energy technology, like offshore wind farms, vertical wind turbines, and floating solar panels, present chances to lessen the environmental effect of energy production while also lessening its effects on ecosystems on land [6]. For example, offshore wind farms can coexist with marine ecosystems and prevent habitat destruction on land [27].

Projects for restoration and reclamation, and renewable energy initiatives may occasionally aid in the repair of the environment. For instance, solar farms that are erected on degraded or abandoned land can produce clean energy and aid in ecosystem rehabilitation [25]. Similar to this, reforestation initiatives in conjunction with the production of bioenergy may foster synergies between the conservation of biodiversity and energy production [35] (**Figure 1**).

2.5. Combining the use of renewable energy with conservation

Planning and Strategic Sitting: The effects on biodiversity can be reduced by strategically placing renewable energy plants. Areas with poor ecological sensitivity can be identified with the use of tools such as GIS-based biodiversity mapping [12]. According to a recent analysis, installing solar panels on damaged areas could help meet the world's energy needs without endangering vital ecosystems [36]. Careful placement to minimize bat habitats and migratory bird pathways is also beneficial for wind energy projects [37]. The idea of "energy sprawl" draws attention to the necessity of coordinated land-use planning to avoid conflicts between conservation objectives and the growth of renewable energy. According to studies, installing renewable energy on lands that have already been degraded or urbanized could greatly lessen the effects on biodiversity while achieving the world's energy goals [10].

Governance and Policy, Long-term sustainability requires that energy policy incorporate biodiversity conservation. In order to guarantee that new projects cause the least amount of ecological disturbance, the EU's Renewable Energy Directive requires environmental studies [11]. Stakeholder participation is best demonstrated by collaborative frameworks such as the Renewable Energy Wildlife Institute in the United States [13]. Furthermore, international accords like the Convention on Biological Diversity (CBD) emphasize the necessity of striking a balance between the conservation of biodiversity and the objectives of renewable energy [18]. Governments are essential in providing incentives for the development of renewable energy sources that support biodiversity. Ecosystem protection and innovation can be achieved through tax credits, subsidies, and regulatory frameworks that give preference to low-impact innovations. Additionally, public-private partnerships provide useful venues for achieving these objectives [38].

Innovations in technology, solutions to lessen ecological footprints, are provided by innovations like bird-safe wind turbines and floating solar panels [16]. Furthermore, improvements in battery storage reduce the amount of land needed to maintain grid stability [39]. New technologies that improve energy efficiency and lessen the need for large land use include bifacial solar panels, which produce power on both sides [40]. The effects of offshore wind farms on marine life are being lessened in the maritime sector thanks to developments in turbine blade design and sound deterrents. In order to lower collision hazards and increase energy generation efficiency, research is being done on bio-inspired engineering, such as wind turbine blades that are shaped like bird wings [17].

2.6. The role of renewable energy on climate change mitigation

Leading the global battle against climate change is renewable energy. Renewable energy sources, including solar, wind, hydropower, and bioenergy, must be adopted if the world is to minimize greenhouse gas emissions. Fossil fuels are the main cause of global warming, yet these technologies provide good substitutes. According to the Intergovernmental Panel on Climate Change (IPCC), switching to renewable energy is crucial to keeping the increase in global temperatures to 1.5 °C over pre-industrial levels [1]. The need to switch to renewable energy is urgent since it can both lower emissions and improve energy security. In addition to producing enormous volumes of carbon dioxide, fossil fuel-based energy systems also put energy supply chains at risk. However, substantial expenditures in infrastructure, research, and innovation are necessary to achieve a low-carbon energy future. For example, over the past ten years, solar and wind energy have seen impressive improvements in efficiency and cost reduction. In many areas, solar photovoltaics and onshore wind have significantly reduced their levelized cost of energy (LCOE), making them competitive with or even less expensive than fossil fuels [9].

The promotion of renewable energy is becoming more and more vital to the global policy environment. Adopted in 2015, the Paris Agreement is a historic pledge to reduce greenhouse gas emissions in order to fight climate change [8]. Countries have established nationally determined contributions (NDCs) within this framework that specify their goals for renewable energy and emission reduction.

Another example of a comprehensive legislative framework designed to increase the deployment of renewable energy is the Renewable Energy Directive of the European Union [34]. Setting enforceable goals for member states to attain a specific percentage of renewable energy in their energy mix, this directive places a strong emphasis on sustainability. In a similar vein, nations like the US, China, and India have put ambitious plans for renewable energy into action to spearhead the worldwide shift. The adoption of renewable energy varies greatly by location, notwithstanding these efforts. Developing nations frequently struggle with issues including restricted access to grid infrastructure, funding, and technology. In order to close these gaps and assist renewable energy initiatives in these areas, international collaboration and financial tools like the Green Climate Fund are essential.

Renewable energy has grown rapidly due in large part to technological breakthroughs. Photovoltaic cells and concentrated solar power systems are two examples of solar energy technologies that have improved efficiency and affordability. In a similar vein, wind turbine designs have improved to better capture wind energy, especially in regions with low wind speeds [10]. Lithium-ion and enhanced flow batteries are two examples of energy storage technologies that are essential for mitigating the intermittent nature of renewable energy sources. These technologies make it possible to store extra energy produced during periods of high production for use during periods of low production. Reliability is increased, and the requirement for fossil fuel backup power is decreased when storage technologies are integrated into renewable energy grids. Energy systems are also being revolutionized by digital solutions and smart grid technologies. Demand-response management, real-time monitoring, and efficient energy distribution are made possible by these advancements. Additionally, smart grids make it easier to incorporate dispersed energy sources into the larger energy system, such as community wind projects and rooftop solar panels.

In addition to reducing global warming, renewable energy has many other advantages. For example, using renewable energy sources lowers air pollution, which has important economic and health effects. The burning of fossil fuels is a significant source of air pollutants such as nitrogen oxides, sulfur dioxide, and particulate matter. Making the switch to sustainable energy sources can lower the prevalence of cardiovascular and respiratory illnesses and greatly improve air quality [11]. Projects using renewable energy also generate revenue. Compared to fossil fuels, the renewable energy industry is labor-intensive and creates more jobs per unit of energy produced. Over 12 million people were engaged worldwide in the renewable energy sector in 2020, according to the International Renewable Energy Agency (IRENA), and this figure is projected to rise as more money is invested in renewable energy sources [12]. Additionally, in isolated and neglected locations, renewable energy can improve electricity availability. For areas without access to centralized power grids, decentralized renewable energy sources like microgrids and off-grid solar solutions supply electricity. This promotes social justice and economic growth in addition to raising living standards.

Renewable energy has many advantages; however, there are drawbacks to its use. The main challenges include resource shortages, land-use conflicts, and technical restrictions. Large-scale solar farms, for instance, demand a lot of land,

which may cause habitat degradation and conflict with farming [25]. In a similar vein, the extraction of rare earth metals and lithium for renewable energy technology has social and environmental ramifications [32]. Researchers and policymakers are looking at creative ways to solve these problems. One strategy that maximizes land use while promoting food and energy production is agrivoltaics, which blends solar energy generation with agriculture [22]. Installed on reservoirs and other bodies of water, floating solar farms provide additional advantages, including less water evaporation and enhanced panel efficiency [11]. To overcome these obstacles, parties must work together. To create and execute policies that support sustainable renewable energy practices, governments, business leaders, academic institutions, and civil society organizations must collaborate. For example, public-private partnerships can pool resources and knowledge to spur innovation and increase the use of renewable energy [36].

Making the switch to a low-carbon economy egalitarian and inclusive is ensured by a just transition to renewable energy. This entails addressing the economic and social effects of moving away from fossil fuels, especially for workers and communities who rely on the fossil fuel sector. A just transition requires policies that promote community growth, social safety nets, and workforce retraining. For instance, in areas that have historically relied on coal mining or oil extraction, investments in renewable energy projects can generate alternative job prospects. Furthermore, community ownership models for renewable energy projects guarantee that the advantages of clean energy are shared fairly and strengthen local communities. Resolving past disparities in energy access is another aspect of the idea of energy justice. An opportunity to close the energy gap and guarantee that underserved populations have access to reasonably priced, dependable, and clean electricity is presented by renewable energy. Prioritizing the needs of disadvantaged people through targeted policies and investments is necessary to achieve energy justice.

Integrating renewable energy with other sustainable development objectives is key to its future. For example, coordinating renewable energy initiatives with biodiversity preservation can result in synergies that advance ecological and climate goals. When combined with sophisticated spatial analysis methods, landscape-level planning can pinpoint locations where the use of renewable energy has the least negative ecological effects [38]. Innovation will be essential to the development of renewable energy technology. Research on bioenergy feedstocks, enhanced wind turbine materials, and next-generation solar cells have the potential to improve sustainability and efficiency. Furthermore, waste may be minimized, and resource consumption can be decreased by developing circular economy models for renewable energy systems. International collaboration will be essential to the global expansion of renewable energy. Financial tools, capacity-building programs, and knowledge-sharing platforms can all aid in closing the gap between industrialized and poor nations. The switch to renewable energy can become a pillar of global climate action by encouraging cooperation. In summary, renewable energy provides a route to a resilient and sustainable future and is essential for mitigating the effects of climate change. However, the values of equality, creativity, and sustainability must direct its implementation. Renewable energy has the potential to be a game-

changer in the worldwide fight against climate change if the obstacles are addressed and the opportunities are taken advantage of.

Moreover, using an environmental impact factor such as carbon footprint (CF) to assess the benefits of renewable energy in mitigating climate change and preserving biodiversity allows for a standardized comparison of different energy sources [1,8]. CF measures greenhouse gas emissions associated with energy production, making it easier to quantify the environmental benefits of renewables like solar, wind, and hydropower compared to fossil fuels. Renewable energy sources significantly reduce CF by replacing carbon-intensive fuels, lowering atmospheric CO₂ levels, and decreasing global warming effects [8,25]. This, in turn, helps preserve ecosystems by reducing habitat destruction caused by climate change, such as coral bleaching, deforestation, and species loss. Lower emissions also minimize air and water pollution, benefiting biodiversity by improving habitat quality [25]. By using CF as a common criterion, policymakers and stakeholders can evaluate the effectiveness of various climate action strategies, prioritize low-impact energy solutions, and set measurable sustainability goals. This approach enhances transparency, supports informed decision-making, and promotes global efforts to combat climate change while safeguarding biodiversity. Ultimately, integrating CF into energy planning fosters a transition to cleaner energy systems, ensuring environmental sustainability and resilience for future generations.

2.7. The role of ecosystems in mitigating climate change

Because they operate as carbon sinks, absorbing and storing atmospheric carbon dioxide (CO₂), ecosystems are essential to reducing the effects of climate change [41]. In this context, soil, marshes, and forests are especially important. Through photosynthesis, forests—particularly tropical rainforests—sequester significant amounts of CO₂, and soil carbon storage is crucial to sustaining the global carbon cycle [1]. Peatlands can store up to one-third of the carbon in the soil on Earth, making them one of the most effective carbon sinks [17]. With mangrove forests storing up to four times more carbon per unit area than terrestrial forests, coastal habitats like salt marshes, seagrass beds, and mangroves are especially essential for sequestering carbon [41]. Additionally, ecosystems with more biodiversity are better able to store carbon and are more resilient to the effects of climate change [20,42]. In order to improve these ecosystems' potential to store carbon and lessen the effects of climate change, while also preserving biodiversity and ecosystem services, it is imperative that they be preserved and restored [42,43].

2.8. Trade-offs between renewable energy and ecosystems

Loss of Habitat and Land Use, Large-scale renewable energy initiatives, such as wind turbines and solar farms, need a lot of land and may intrude on natural areas [14,15]. Developments in wind energy in the United States have affected important bird migration pathways, leading to higher mortality rates, according to a 2021 study [44]. In dry areas, solar farms have the potential to disrupt delicate desert ecosystems [45]. When grown on a big scale, land-intensive bioenergy crops like oil palms and maize worsen habitat loss [9]. Integrated land-use planning is necessary to balance

biodiversity conservation with the land requirements of renewable energy. Innovative approaches that combine solar energy generation with agricultural practices, such as agrovoltatics, present intriguing ways to maximize land usage while reducing environmental trade-offs [46].

Offshore Renewables' Effects on the Marine Environment: Although they have significant energy potential, offshore wind farms have the potential to disturb marine ecosystems [22]. Fish migration patterns can be changed by turbine blades, and marine mammals are impacted by noise pollution during construction [47]. It is crucial to implement mitigation strategies like exclusion zones and quieter construction technologies [47]. The multiple impacts of offshore wind farms are highlighted by the fact that they can produce artificial reef structures that promote marine biodiversity [44,47]. For marine biodiversity, the development of tidal and wave energy technology brings both new opportunities and challenges. The undersea infrastructure of these technologies can disrupt the natural habitats and behaviors of marine creatures, even though their visual consequences are less than those of offshore wind. To reduce these effects, adaptive management techniques and strategic siting are crucial [46,47].

3. Future directions

Future research should focus on optimizing renewable energy site selection using advanced Geographic Information Systems (GIS) and remote sensing to minimize habitat destruction. Developing biodiversity-friendly technologies, such as bird-friendly wind turbines and fish-friendly hydropower systems, can help reduce ecological impacts. Additionally, sustainable resource extraction methods for materials like lithium and rare earth elements must be prioritized to prevent habitat degradation. Stronger policy integration is needed, ensuring that renewable energy expansion aligns with conservation strategies. This includes enhancing environmental impact assessments (EIAs) and promoting ecological compensation measures. Community engagement and indigenous knowledge should also play a crucial role in planning renewable energy projects to balance development with local ecosystem protection. Finally, interdisciplinary collaborations between energy developers, conservationists, and policymakers can lead to innovative solutions that maximize climate benefits while safeguarding biodiversity. Addressing these challenges will be essential for a truly sustainable energy transition.

4. Conclusion

Transitioning to renewable energy is essential for mitigating climate change, but its potential impacts on biodiversity must be carefully managed. While solar, wind, hydropower, and bioenergy significantly reduce greenhouse gas emissions, their large-scale deployment can lead to habitat destruction, species displacement, and ecosystem fragmentation if not properly planned. Addressing these challenges requires a comprehensive approach that integrates energy development with biodiversity conservation. Strategic site selection, particularly avoiding ecologically sensitive areas, is crucial in minimizing environmental harm. Technologies such as floating solar farms, offshore wind farms, and sustainable bioenergy practices can

reduce land-use conflicts and ecological disruption. Additionally, innovations like bird-friendly wind turbines and fish-friendly hydropower systems can help mitigate species loss. Strengthening environmental impact assessments (EIAs) and ensuring compliance with biodiversity protection regulations will be key to balancing energy expansion with conservation. Policymakers must prioritize biodiversity alongside energy development to ensure that climate goals do not come at the cost of ecosystem health. Integrating biodiversity safeguards into energy policies, promoting ecological compensation measures, and encouraging interdisciplinary collaboration among scientists, conservationists, and energy developers are necessary steps toward a balanced approach. Community engagement and the incorporation of indigenous knowledge can further enhance the sustainability of renewable energy projects. As the world continues to scale up renewable energy, developing comprehensive guidelines and best practices is essential to aligning energy production with ecosystem protection. By adopting a multidisciplinary, ecosystem-based approach, it is possible to expand renewable energy while preserving biodiversity. Protecting ecosystems not only strengthens resilience against climate change but also ensures long-term environmental sustainability and human well-being. A holistic approach that considers both climate and biodiversity will be critical for achieving a truly sustainable energy transition.

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