RESEARCH ARTICLE

Mainstreaming Biodiversity into Power Sector Planning and Policy to Deliver Better Outcomes for Nature and the Climate

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Abstract

The research aims to investigate how India's current power sector planning and policy frameworks can be adapted to incorporate biodiversity considerations. It will identify the biodiversity impacts of renewable energy projects, examine the economic and social co-benefits of integrating biodiversity, and assess the challenges and potential solutions for implementing biodiversity-inclusive policies. The study employs a secondary data approach, analyzing national and state-level energy policies, regulatory frameworks, environmental guidelines, academic papers, case studies, and reports from global organizations. It includes a policy review, literature review, biodiversity impact assessment, stakeholder perspectives analysis, and economic and environmental co-benefits evaluation. Data integration and analysis are used to develop a framework for integrating biodiversity into India's power sector policy and planning. The research identifies significant gaps in current policies regarding biodiversity inclusion, such as inadequate biodiversity impact assessments, regulatory inconsistencies, and a lack of cross-sectoral coordination. It highlights the need for policy amendments, best practice guidelines, and collaborative approaches among government, the private sector, and conservation NGOs. The study also underscores the importance of conducting comprehensive environmental impact assessments, utilizing spatial planning approaches, and fostering partnerships to address biodiversity impacts. The research concludes that India's power sector must evolve to include biodiversity considerations as a central component of its planning and policy framework. By doing so, the country can achieve its energy goals while safeguarding its invaluable natural heritage, ensuring a harmonious coexistence between development and nature.

Key Words: *Biodiversity; Power sector planning; Policy integration; Renewable energy; Biodiversity Impact Assessment (BIA); Habitat restoration; India*

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1. Introduction

India stands at the crossroads of rapid energy development and the urgent need to conserve its rich biodiversity. As the nation seeks to meet its growing energy demands, particularly through renewable energy sources, it also faces significant environmental challenges. The power sector, a key player in this development, has the potential to cause profound harm to ecosystems if biodiversity considerations are not integrated into its planning and policy frameworks [1]. This highlights the need for mainstreaming biodiversity into the power sector to ensure both energy security and ecological sustainability.

India's biodiversity is one of the most diverse in the world, hosting four global biodiversity hotspots and more than 11% of the world's floral and faunal species [2]. However, the nation's push toward energy expansion, particularly with renewable sources like wind and solar, poses a threat to this natural heritage. Renewable energy projects, although vital for reducing greenhouse gas emissions, can disrupt ecosystems, alter land use, and cause habitat loss, especially when not planned with environmental safeguards [3]. Hydropower plants, for instance, can fragment rivers and disrupt fish migration, while large solar farms can lead to significant land degradation [4].

Despite these challenges, India has a unique opportunity to align its energy transition goals with biodiversity conservation. Integrating biodiversity into power sector planning can offer multiple benefits, both for nature and people. Careful siting of renewable energy projects, for example, can mitigate negative impacts on critical ecosystems while promoting ecosystem services such as water purification and flood control, which in turn support community resilience to climate change [5,6]. Furthermore, promoting biodiversity-inclusive energy development could unlock new revenue streams through ecotourism and sustainable agriculture, contributing to long-term economic growth [7].

International examples provide valuable lessons for India's energy transition. Costa Rica's geothermal energy initiatives have been successfully paired with biodiversity conservation efforts, demonstrating that energy production and environmental protection can coexist harmoniously [8]. Similarly, Germany has integrated environmental assessments into its renewable energy policies, ensuring that biodiversity concerns are addressed during project planning and implementation [9]. These global best practices underscore the importance of balancing renewable energy development with biodiversity preservation, a challenge that India must navigate as it aims to meet its ambitious renewable energy targets.

The need to reconcile energy production with biodiversity conservation is further underscored by the growing body of research highlighting the risks of ignoring biodiversity in energy planning. Failure to do so can lead to unintended consequences, such as the destruction of biodiversity-rich areas that are crucial for sustaining ecosystem services and human livelihoods [10]. Therefore, mainstreaming biodiversity into power sector planning is not just an environmental imperative but also a strategic investment in India's sustainable future [11].

In conclusion, India's power sector must evolve to include biodiversity considerations as a central component of its planning and policy framework. By doing so, the country can achieve its energy goals while safeguarding its invaluable natural heritage, ensuring a harmonious coexistence between development and nature.

2. Literature Review

2.1. The energy-biodiversity nexus

The energy sector's rapid expansion poses significant risks to biodiversity. As countries like India aim to meet their energy demands through renewable sources such as solar, wind, and hydropower, the potential impacts on ecosystems are substantial [3]. Several studies have highlighted the urgent need to integrate biodiversity considerations into energy planning. For instance, Khera, et al. [1] emphasized the lack of biodiversity integration in environmental impact assessments (EIA) for Indian projects. This gap is concerning, given India's status as one of the most biodiverse countries, home to four global biodiversity [2]. Similarly, Odunaiya, et al. [12] reviewed the potential conflicts between renewable energy development and wildlife conservation, suggesting strategies to mitigate these tensions. The expansion of renewable energy, while essential for mitigating climate change, has been linked to habitat destruction and ecosystem fragmentation [13]. Hydropower plants, for example, fragment rivers and disrupt aquatic life, as highlighted by Lange, et al. [14]. Wind and solar farms can lead to land-use changes, affecting wildlife habitats and migration routes [4,15]. These challenges are particularly pronounced in countries like India, where energy demands are rapidly increasing [16].

2.2. Global best practices for integrating biodiversity into energy planning

Countries such as Costa Rica and Germany have successfully integrated biodiversity considerations into their renewable energy policies. Costa Rica's geothermal energy projects have incorporated biodiversity conservation measures, ensuring minimal environmental disruption [8]. Germany's rigorous environmental assessments for renewable energy projects have been instrumental in minimizing biodiversity loss [9]. These examples highlight the potential for countries to harmonize energy development with biodiversity preservation.

The need for biodiversity-inclusive energy planning is further supported by Bennun, et al. [6], who developed guidelines for project developers to mitigate biodiversity impacts. Their work stresses the importance of spatial planning to avoid critical habitats and ensure that renewable energy projects are sited in areas of lower ecological importance. This aligns with the findings of Santangeli, et al. [10], who identified trade-offs between renewable energy expansion and biodiversity conservation. Their cross-national analysis emphasized that energy projects must be tailored to local ecological conditions to minimize negative impacts.

2.3. Challenges and gaps in India's energy and biodiversity policy

India's National Action Plan on Climate Change (NAPCC) promotes renewable energy as a key strategy for mitigating climate change [17]. However, the country's energy policies have historically overlooked biodiversity concerns, as noted by Kiesecker, et al. [18]. Renewable energy projects, particularly in biodiversity-rich areas, have led to habitat destruction and species displacement [16]. For example, wind energy projects in the Western Ghats have been linked to bird and bat fatalities, illustrating the ecological risks associated with poorly planned renewable energy projects [19].

A key challenge in India is the lack of robust biodiversity-inclusive policies. Gasparatos, et al. [7] pointed out that while India has made strides in renewable energy, its policies fail to adequately address the ecological impacts of energy projects.

This is compounded by regulatory inconsistencies, as highlighted by Opperman, et al. [20], who noted that India's hydropower projects often proceed without comprehensive biodiversity assessments.

2.4. Synergies and trade-offs between renewable energy and biodiversity

The relationship between renewable energy and biodiversity is complex, characterized by both synergies and trade-offs. Several studies have explored how energy mitigation strategies can either support or undermine biodiversity conservation efforts. Berry, et al. [21] highlighted the potential synergies between climate mitigation and biodiversity preservation, suggesting that carefully planned renewable energy projects could contribute to both goals. However, Santangeli, et al. [22] identified significant trade-offs, noting that rapid renewable energy expansion often prioritizes climate goals at the expense of biodiversity.

Rehbein, et al. [13] similarly noted that many renewable energy projects threaten globally significant biodiversity areas. Their study called for more integrated approaches to energy development that consider both climate and biodiversity outcomes. In India, the integration of biodiversity into energy planning remains limited, despite the potential co-benefits of such an approach [11].

2.5. Strategies for biodiversity-inclusive energy development

Several strategies have been proposed to reconcile the goals of renewable energy expansion and biodiversity conservation. Bennun, et al. [6] proposed spatial planning approaches that prioritize low-impact zones for energy development. Similarly, Jager, et al. [23] advocated for ecosystem-based approaches to energy planning, which would involve selecting sites based on their ecological value. This approach is supported by Ledec, et al. [24], who recommended that wind energy projects be sited away from migratory bird routes to minimize biodiversity impacts.

Cameron, et al. [25] suggested enhancing the conservation compatibility of solar energy projects by integrating habitat restoration measures into project design. Additionally, Vergez [26] proposed a more holistic approach to energy policy, where biodiversity is mainstreamed across all stages of energy development, from planning to operation.

2.6. Economic and social co-benefits of biodiversity mainstreaming

Mainstreaming biodiversity into energy planning can also offer economic and social co-benefits. TEEB [5] demonstrated that ecosystems provide essential services such as water purification and climate regulation, which can support both energy security and community resilience. Similarly, Smith, et al. [27] highlighted the potential for biodiversity-inclusive energy projects to generate economic benefits through ecotourism and sustainable agriculture.

McShane, et al. [28] emphasized the importance of community engagement in biodiversity conservation, noting that local communities are often the primary beneficiaries of ecosystem services. This aligns with the findings of Ginoya, et al. [29], who argued that integrating energy priorities with community needs can enhance the social acceptability of renewable energy projects.

2.7. Critical review of literature

To address the challenges of integrating biodiversity into India's energy sector, several recommendations emerge from the literature. First, India must strengthen its environmental impact assessments (EIA) to include comprehensive biodiversity assessments [1]. Second, spatial planning tools should be developed to identify low-impact zones for renewable energy projects [6]. Third, policymakers should adopt ecosystem-based approaches to energy development, ensuring that projects are tailored to local ecological conditions [23].

The development of biodiversity-inclusive energy policies could also unlock economic opportunities, particularly in sectors such as ecotourism and sustainable agriculture [5]. Moreover, integrating biodiversity into energy planning could enhance community resilience to climate change, as ecosystems play a crucial role in regulating water cycles and mitigating natural disasters [27].

The literature underscores the urgent need to integrate biodiversity into energy planning, particularly in rapidly developing countries like India. While renewable energy is essential for reducing carbon emissions, it must be carefully planned to avoid unintended ecological consequences. By mainstreaming biodiversity into power sector policies, India can achieve its energy goals while safeguarding its rich natural heritage. Global best practices, such as those from Costa Rica and Germany, offer valuable lessons for India as it seeks to harmonize energy development with biodiversity conservation.

The path forward involves strengthening environmental assessments, adopting spatial planning tools, and engaging local communities in energy planning. By doing so, India can create a power sector that not only meets its energy demands but also contributes to long-term ecological sustainability and social well-being.

3. Methodology

This research employs a secondary data approach to analyze existing information from various sources regarding the intersection of biodiversity and power sector development in India. The methodology consists of several key components.

Policy Review involves analyzing national and state-level energy policies, regulatory frameworks, and environmental guidelines. These documents will be sourced from government websites, international energy agencies, and environmental organizations. The analysis will focus on identifying gaps in current policies related to biodiversity inclusion and will include a comparative analysis with international biodiversity-inclusive energy frameworks, such as those of Costa Rica and Germany.

Literature Review will encompass academic papers, case studies, and reports from global organizations like the Convention on Biological Diversity (CBD), the Organisation for Economic Co-operation and Development (OECD), and the World Resources Institute (WRI). Relevant studies will be gathered using databases such as Scopus, Google Scholar, and institutional archives. The synthesis of existing research aims to reveal patterns of biodiversity loss due to energy development, identify best practices for mitigation, and explore the potential for ecosystem service restoration.

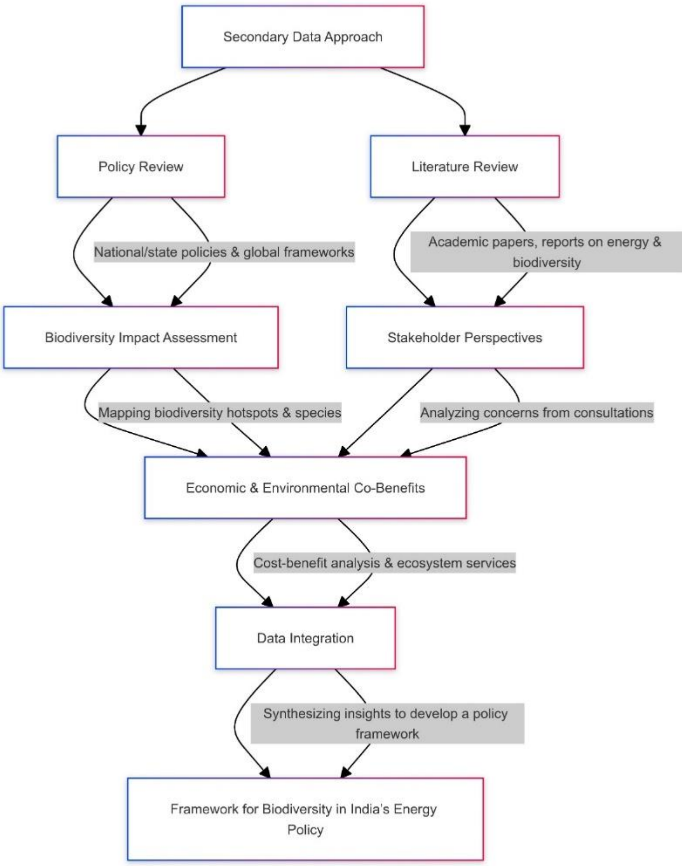

Figure 1: *Framework for biodiversity in India's energy policy.*

Biodiversity impact assessment will utilize published ecological assessments, geospatial studies, and reports on biodiversity hotspots from environmental agencies and monitoring organizations. Spatial data from these studies will be mapped to identify critical biodiversity areas impacted by energy projects. Additionally, secondary ecological surveys and reports will be analyzed to assess species populations and habitat disruption.

Stakeholder Perspectives will be gathered through secondary interviews and reports from prior consultations with various stakeholders, including government officials, energy companies, conservation groups, and affected communities. The analysis will draw from reports of workshops, policy dialogues, and stakeholder engagement programs to identify and categorize themes related to stakeholder concerns about biodiversity in energy development. Economic and Environmental Co-Benefits will be assessed using existing cost-benefit analyses, market valuation studies, and ecosystem service models from reports by global organizations such as The Economics of Ecosystems and Biodiversity (TEEB) and the United Nations Environment Programme (UNEP). This analysis will synthesize data on the economic value of biodiversity—such as water purification and carbon sequestration—as well as the social benefits of biodiversity-inclusive development, like climate resilience and community well-being.

Finally, Data Integration and Analysis will involve synthesizing data from all the aforementioned secondary sources. This stage will analyze patterns, trends, and correlations between power sector policies, biodiversity impacts, and stakeholder concerns. A framework will be developed to integrate biodiversity considerations into India's energy policy based on the collected secondary data.

3.1. Criteria for choosing methodology and analytical framework

To address the criteria for literature selection and the analytical framework used in this study, it is essential to clarify the approach taken to ensure academic rigor and relevance. The literature reviewed was selected based on five key criteria. First, relevance to the core research question was prioritized; only sources that directly examined the intersection of biodiversity and energy infrastructure—particularly in the Indian context—were included. Second, the credibility of sources was a crucial filter. Peer-reviewed journal articles, official policy documents, and reports from reputable international organizations such as the OECD, WRI, and CBD formed the primary basis of analysis. Grey literature was included only when it provided unique, context-specific insights that were otherwise unavailable. Third, the temporal scope was generally limited to the last 15 years to ensure contemporary relevance, although older foundational studies were retained when they continued to inform current discourse [5]. Fourth, geographic applicability was taken into account; while the focus was on India, international experiences—such as those of Germany and Costa Rica—were examined for comparative insight and to extract best practices transferable to the Indian context. Lastly, thematic breadth was maintained to encompass diverse dimensions such as biodiversity impact assessments, spatial planning, policy integration, and socio-economic co-benefits.

The analytical framework guiding this study was built on a qualitative synthesis approach structured across five interrelated dimensions. First, a policy gap analysis was conducted to identify omissions or inconsistencies in India’s current power sector and biodiversity policies by comparing them against global benchmarks. Second, a thematic coding approach was employed to analyze the literature, grouping content into recurring issues such as habitat fragmentation, stakeholder resistance, and deficiencies in environmental impact assessments. Third, international case studies were subjected to comparative analysis, offering a lens to evaluate India’s performance and opportunities for policy alignment. Fourth, the study mapped the economic and social co-benefits of biodiversity-inclusive energy development using synthesized data on ecosystem services such as carbon sequestration, water purification, and climate resilience. Finally, findings from these multiple strands were integrated into a conceptual policy-planning matrix (illustrated in Figure 1 of the paper), aligning ecological, policy, social, and economic considerations. This integrative approach enabled the study to move beyond descriptive analysis and provide actionable insights for mainstreaming biodiversity into India’s power sector planning and policy.

4. Assessment

4.1. Policy review: gaps in biodiversity inclusion in India’s energy sector

India’s current energy policies, especially those focused on renewable energy, emphasize scaling up renewable energy capacity to meet climate targets. However, these policies often lack comprehensive biodiversity considerations. The push for renewable energy, particularly solar and wind projects, has introduced potential threats to biodiversity due to land-use changes, habitat fragmentation, and impacts on local ecosystems, as outlined by Bennun, et al. [6] and Kiesecker, et al. [30].

4.1.1. Gaps in India's current policies

- **Inadequate integration of biodiversity in energy planning:** Indian renewable energy policies like the National Action Plan on Climate Change (NAPCC) prioritize energy generation targets but often under-represent biodiversity impacts in project planning and

Environmental Impact Assessments (EIAs). While EIAs are mandated for large projects, the scope and enforcement are limited, often missing biodiversity-inclusive impact assessments. Khera, et al. [1] observed that EIA reports in India frequently overlook key biodiversity metrics.

- **Lack of cross-sectoral coordination:** India's policies largely operate in silos, with limited integration between the energy and environmental sectors. This hinders a holistic approach to mitigating biodiversity risks. The absence of cohesive frameworks that jointly address energy production and conservation needs results in unintended biodiversity losses.

- **Minimal focus on restoration or offsetting:** India's renewable energy policies lack clear guidelines on biodiversity offsets or habitat restoration post-project completion, which are essential to mitigate long-term ecological damage. As suggested by Hardner, et al. [9], biodiversity-inclusive management planning is critical in minimizing these adverse impacts.

4.1.2. Comparative analysis with international frameworks

Germany and Costa Rica present strong examples of biodiversity-inclusive energy frameworks, showcasing how renewable energy expansion can be integrated with conservation efforts.

- **Germany:** Germany's Renewable Energy Sources Act (EEG) includes stringent biodiversity standards for renewable projects. The country ensures that renewable energy projects undergo rigorous biodiversity assessments before implementation. Furthermore, policies such as the Renewable Energy Law explicitly encourage biodiversity restoration through compensatory measures like habitat corridors and wildlife-friendly project designs. These measures highlight the importance of proactive biodiversity conservation in energy infrastructure planning.

- **Costa Rica:** Costa Rica's National Biodiversity Strategy integrates renewable energy expansion with environmental conservation goals. The country has successfully expanded its renewable energy capacity, particularly hydropower, while ensuring minimal biodiversity loss by leveraging environmental safeguards and emphasizing sustainable land-use practices. Additionally, Costa Rica's Payment for Ecosystem Services (PES) program compensates landowners for biodiversity conservation, aligning energy development with ecosystem preservation.

4.1.3. Key policy recommendations for India

- **Adopt biodiversity-inclusive EIAs:** Indian renewable energy policies must mandate biodiversity-inclusive EIAs with well-defined frameworks similar to those in Germany and Costa Rica. Strengthening the EIA process will ensure that biodiversity risks are identified and mitigated at early stages.

- **Enhance cross-sectoral coordination:** Like Costa Rica's approach, India should promote cross-sectoral collaboration between energy, forestry, and biodiversity sectors to create integrated land-use plans that address both energy needs and biodiversity conservation.

- **Develop compensatory mechanisms:** Drawing from Germany's biodiversity compensation strategies, India can implement biodiversity offsets and restoration mandates for renewable energy projects to counterbalance biodiversity losses.

Addressing these policy gaps is essential for India to not only meet its climate goals but also preserve its rich biodiversity heritage.

4.2. Biodiversity assessment: evaluate impacts of existing power sector activities on ecosystems

Table 1: *Summary of research on biodiversity loss, mitigation, and ecosystem restoration in energy development sector.*

Area of focus	Research findings	Best practices for mitigation	Potential for ecosystem service restoration
International context			
Biodiversity Loss due to Energy Development	Renewable energy projects like solar, wind, and hydropower can significantly impact biodiversity through habitat destruction, fragmentation, and species displacement [6,10].	Conducting biodiversity-inclusive Environmental Impact Assessments (EIAs) prior to project approvals, and siting projects away from sensitive habitats [1,9].	Renewable energy projects can help restore ecosystems by minimizing land use impact, integrating nature corridors, and rehabilitating degraded areas post-construction [25,31].
Habitat Fragmentation	Large-scale renewable energy projects, such as solar farms and wind turbines, can fragment habitats, posing significant risks to wildlife populations and migratory species [13].	Integrated landscape planning can help avoid critical biodiversity areas and migration corridors [20]. Cross-sectoral cooperation is vital to balance development and conservation [32].	By restoring connectivity through wildlife corridors or habitat compensation, energy projects can promote the recovery of ecosystems impacted by fragmentation [33].
Species Displacement	Energy infrastructure development often leads to the displacement of species from their natural habitats, leading to population declines [12,18].	Mitigation techniques like creating buffer zones and minimizing noise, light, and construction impacts [24].	Reforestation, wetland restoration, and other habitat reconstruction methods can facilitate ecosystem services like carbon sequestration, water purification, and biodiversity recovery [2,34].

Water and River Systems	Hydropower projects are major contributors to the loss of riverine ecosystems and freshwater biodiversity, disrupting fish migration and altering water quality [14].	Implementing fish ladders, maintaining environmental flows, and conducting ecosystem-based water management [20].	Restoring river connectivity and riparian habitats through dam removal or fish passage technologies offers potential for ecosystem recovery [23].
Invasive Species Introduction	Infrastructure projects can unintentionally introduce invasive species that threaten local biodiversity [7].	Monitoring and control measures for invasive species during and after construction phases [15].	Rehabilitation of native plant and animal species post-project completion can restore ecosystem balance [35].
Indian context			
Cumulative Impact	The cumulative effects of multiple renewable energy projects can lead to widespread ecosystem degradation if not properly managed [16].	Coordinated planning at regional scales to minimize cumulative biodiversity impacts and implementing biodiversity offsets [7,31].	Through proper cumulative impact assessments and management, renewable projects can be designed to enhance rather than degrade ecosystem services, especially in degraded areas [26].
Biodiversity Risks in Renewable Energy Investments in India [11]	Renewable energy projects, especially in solar and wind, pose significant risks to biodiversity in India.	Prioritizing site selection away from ecologically sensitive areas; Environmental Impact Assessments (EIAs).	Restoring habitat through compensation measures, like reforestation or wildlife corridors.
Inclusion of Biodiversity in Environmental Impact Assessments (EIA) [1]	EIAs often fail to fully incorporate biodiversity considerations in India's energy projects.	Updating and enforcing more stringent biodiversity-focused EIA standards.	Integrating ecosystem service valuation in energy project planning to restore lost services.
Mitigating Biodiversity Impacts from Solar and Wind Development [6].	Guidelines for reducing the biodiversity impact of solar and wind projects.	Use of habitat compensation, adaptive management, and monitoring biodiversity impacts.	Promoting natural habitat restoration projects alongside renewable energy development.
Renewable Energy Development and Biodiversity Conflicts [10].	There are synergies and trade-offs between renewable energy expansion and biodiversity conservation.	Implementing strategic environmental assessments to address	Promoting the restoration of ecosystems through

		biodiversity impacts during project planning.	biodiversity offsets in impacted areas.
Challenges from Increasing Renewable Energy in India [16].	Increasing renewable energy generation poses new challenges for grid stability and biodiversity conservation.	Adopting technologies that minimize land use and fragmentation of natural habitats.	Supporting rewilding initiatives to restore ecosystems fragmented by energy infrastructure.
Renewable Energy and Land Use in India [18].	Large land footprints of renewable energy infrastructure create conflict with biodiversity conservation efforts.	Implementing landscape-level planning to minimize biodiversity disruption.	Initiatives for landscape rehabilitation and creating buffer zones around energy projects.
Integrating Renewable Energy and Wildlife Conservation [12]	Reviews conflicts and coexistence strategies between renewable energy policies and wildlife conservation in India.	Encouraging the use of multi-use landscapes, where energy projects coexist with conservation efforts.	Ecosystem service restoration can be achieved by promoting conservation-focused land management.

4.2.1. Biodiversity impact assessment

Table 2: *Biodiversity Impact Assessment (BIA).*

Biodiversity area	Energy project impact	Species affected	Ecological Surveys/Reports	Citations
Aravalli Hills	Wind Farms	Leopards, indigenous flora	Noise pollution, displacement of local wildlife	Kiesecker, et al. [36].
Arunachal Pradesh (Eastern Himalayas)	Habitat fragmentation due to small hydropower plants	Snow leopards, red pandas, various bird species	Impact of small-scale hydropower projects on mountainous biodiversity	Lange, et al. [14] .
Gujarat (Coastal regions)	Loss of migratory bird habitats due to wind turbines	Flamingos, migratory seabirds	Reports from Bennun, et al. [6] on avian mortality associated with wind farms	Bennun, et al. [6].
Himalayan Foothills	Hydropower Projects	Snow leopards, Himalayan tahr	Alteration of river ecosystems, deforestation	Khera, et al. [1].
North-eastern India	Small Hydropower Projects	Aquatic biodiversity, migratory fish species	Reduced water quality, flow alterations	Lange, et al. [14].
Rajasthan Desert	Solar Projects	Desert fox, Great Indian Bustard	Habitat loss due to large-scale solar farms	Bennun, et al. [6].

Sundarbans	Impact of offshore wind projects on mangrove ecosystems	Bengal tigers, saltwater crocodiles, river dolphins	wind energy development near sensitive coastal areas	Palchak, et al. [37].
Thar Desert	Habitat disruption due to solar power plants	Desert foxes, caracals, and various reptile species	impact of solar energy projects on habitat fragmentation	Bennun, et al. [6].
Western Ghats	Deforestation due to hydropower and wind projects	Endemic amphibians, tigers, and elephants	Reports on species displacement in response to hydropower development	Kiesecker, et al. [18].
	Wind and Solar Projects	Elephants, endemic bird species		Rehbein, et al. [13].

4.3. Stakeholder engagement concerns and challenges

Table 3: *Stakeholder concerns and challenges.*

Theme	Stakeholder concerns and challenges	Citations
Biodiversity Impacts of Renewable Energy Projects	Stakeholders are concerned about the impact of renewable energy projects, such as wind and solar farms, on biodiversity. These projects often result in habitat loss, fragmentation, and pose threats to wildlife.	Bennun, et al. [6]; Gasparatos, et al. [7]; Rehbein, et al. [13]; Lange, et al. [14]; Bulling, et al. [15]; Kiesecker, et al. [18].
Climate-Biodiversity Nexus	Stakeholders recognize the interconnectedness of climate action and biodiversity protection, advocating for frameworks that address both issues together.	Bawa, et al. [31]; Newell, et al. [33]; Gorman, et al. [34].
Community Participation	Stakeholders stress the importance of engaging local communities in biodiversity conservation and energy planning, ensuring inclusive decision-making.	Vergez, [26]; McShane, et al. [28].
Conflicts Between Renewable Energy Development and Conservation	Stakeholders emphasize the conflict between expanding renewable energy infrastructure and biodiversity conservation, highlighting the need for better land-use planning to minimize biodiversity risks.	Santangeli, et al. [10]; Odunaiya, et al. [12]; Rehbein, et al. [13]; Debnath, et al. [16]; Kiesecker, et al. [18]; Palchak, et al. [37].
Cumulative Impacts on Biodiversity	Cumulative impacts from multiple projects pose risks to biodiversity, especially in ecologically sensitive regions. Stakeholders urge for cumulative impact assessments and more effective mitigation strategies.	Cameron, et al. [25]; McShane, et al. [28]; Kiesecker, et al. [30]; Bawa, et al. [31].

EIA and Biodiversity Inclusion	The inclusion of biodiversity in Environmental Impact Assessments (EIA) is often inadequate, and stakeholders demand better integration of biodiversity assessments in the planning stages.	Khera, et al. [1]; Hardner, et al. [9].
Environmental Impact Assessments (EIAs)	Inadequate consideration of biodiversity in Environmental Impact Assessments (EIAs) for energy projects, leading to poor mitigation strategies and biodiversity loss.	Khera, et al. [1]; Hardner, et al. [9]; Ledec, et al. [24].
Hydropower and Riverine Ecosystems	Hydropower projects threaten river ecosystems, and stakeholders call for a shift towards more sustainable planning of hydropower infrastructure.	Lange, et al. (2018) [14]; Opperman, et al. [20].
Impact of Solar and Wind on Ecosystems	Concerns regarding the large land footprints of solar farms and wind energy projects, leading to habitat fragmentation.	Degen, et al. [4]; Jager, et al. [23].
Integration of Biodiversity in National Planning	The integration of biodiversity considerations into national energy and climate plans remains a challenge. Stakeholders push for more cohesive frameworks that address both energy development and biodiversity conservation.	WRI [8]; Vergez [26]; Bawa, et al. [31]; Palchak, et al. [37]; CBD [38]; Chaplin-Harvey, et al. [39].
Land Use Conflicts	Issues arising from the land use demands of renewable energy projects, particularly in biodiversity-rich areas such as forests and grasslands.	Rehbein, et al. [13]; Kiesecker, et al. [18]; Palchak, et al. [37].
Mitigation and Adaptation Strategies	Stakeholders prioritize effective mitigation strategies, including habitat restoration, wildlife corridors, and biodiversity offsets to balance energy development with conservation.	Bennun, et al. [6]; Newell, et al. [33]; Kiesecker, et al. [34].
Mitigation Strategies for Wildlife	Stakeholders demand effective mitigation strategies to protect wildlife affected by energy infrastructure, particularly in wind and solar power projects.	Odunaiya, et al. [12]; Ledec, et al. [24]; Inger, et al. [40].
Monitoring and Enforcement	Stakeholders point to inadequate monitoring of biodiversity impacts post-project implementation and weak enforcement of environmental regulations.	Gasparatos, et al. [7]; McShane, et al. [28]; Kiesecker, et al. [30].
Policy Gaps and Recommendations	There is a lack of comprehensive policies integrating biodiversity conservation into energy sector planning. Stakeholders suggest policies that balance energy goals with biodiversity preservation and climate targets.	OECD [3]; TEEB [5]; Smith, et al. [27]; Das, et al. [41]; Gazdag [42].
Policy Integration of Biodiversity	There is a need for better policy frameworks that integrate biodiversity protection into energy	OECD [3]; Gasparatos et al. [7]; WRI [8].

	development plans. Stakeholders also call for clearer regulatory guidelines.	
Regulatory and Policy Gaps	Stakeholders highlight the lack of comprehensive policies that address both energy development and biodiversity conservation, calling for better regulatory frameworks.	OECD (2024) [3]; Odunaiya, et al. [12]; Elavarasan, et al. [43].
Synergies and Trade-offs	Stakeholders highlight the need to identify synergies between climate mitigation and biodiversity conservation, while also managing trade-offs between renewable energy expansion and the conservation of ecosystems.	Santangeli, et al. [10]; Cameron, et al. [25]; Gorman, et al. [34]; Smith, et al. [35]; ; Ma, et al. [44].
Technological Innovation	The need for technology to mitigate biodiversity risks, including advancements in wind-solar hybrid systems and biodiversity-friendly design for renewable energy infrastructure.	Opperman, et al. [20]; Cameron, et al. [25]; Kumar, et al. [45].
Trade-offs and Synergies in Energy Development	Stakeholders highlight the trade-offs between expanding renewable energy capacity and preserving biodiversity. Some advocate for balancing synergies between energy projects and biodiversity conservation.	Santangeli, et al. [10], Smith, et al. [27].

4.4. Co-benefits

Table 4: *Economic and environmental co-benefits.*

Biodiversity function	**Economic value**	**Social benefits**	**Co-benefits for development**	**Sources**
Carbon Sequestration	Forests and other ecosystems act as carbon sinks, storing CO2 and helping mitigate climate change. This has a direct economic value in carbon credits and offsets.	Supports climate resilience, especially for vulnerable communities, reducing the impact of extreme weather events.	Contributes to national and international climate goals while supporting sustainable rural livelihoods.	OECD [3]; Bawa, et al. [31].
Climate Resilience	Ecosystem services help buffer the impacts of extreme climate events, reducing the need for costly disaster relief efforts and infrastructure damage.	Enhances the resilience of local communities to floods, droughts, and storms, particularly in coastal and mountain regions.	Protecting biodiversity helps communities adapt to climate change, ensuring long-term social and economic stability.	Smith, et al. [35].

Community Well-being and Health	Diverse ecosystems contribute to healthier environments, reducing air and water pollution, which lowers healthcare costs.	Improves overall quality of life, mental health, and recreational opportunities for urban and rural populations.	Biodiversity-inclusive development leads to healthier communities, reducing the strain on public health systems.	OECD [3]; Bawa, et al. [31].
Cultural and Ecotourism Value	Biodiverse regions, like national parks and sanctuaries, attract ecotourism, generating significant income for local communities and governments.	Provides employment and cultural connection for indigenous and local communities, enhancing well-being and preserving traditional knowledge.	Ecotourism promotes biodiversity-friendly development and boosts the rural economy while conserving natural landscapes.	Bennun, et al. [6]; OECD [32].
Pollination Services	Biodiversity, particularly insect species, plays a critical role in pollinating crops, valued at billions of rupees annually in agricultural output.	Ensures crop yields, which supports rural economies and food security.	Enhancing pollinator populations leads to resilient farming systems that depend less on artificial interventions.	Khera et al. (2010) [1]; Gasparatos, et al. [7].
Soil Fertility and Erosion Control	Biodiverse ecosystems prevent soil erosion and improve fertility, which enhances agricultural productivity, reducing the need for fertilizers.	Sustains agricultural livelihoods, particularly for smallholder farmers, improving food security and income.	Reducing reliance on chemical inputs also reduces pollution and supports sustainable farming practices.	Smith, et al. [27].
Water Purification	Biodiversity-rich ecosystems, like wetlands, enhance water quality by filtering pollutants, reducing the need for costly water treatment facilities.	Improves access to clean water for communities, reducing waterborne diseases and enhancing public health.	Biodiversity conservation reduces infrastructure costs and enhances water security in rural and urban areas.	TEEB [5]; Berry, et al. [21].

5. Findings and Analysis

5.1. Policy gaps: identify areas where current power sector policies fail to consider biodiversity

The findings reveal several key areas where India's current power sector policies fall short in considering biodiversity:

- **Inadequate integration of biodiversity in energy planning:** Indian renewable energy policies, such as the National Action Plan on Climate Change (NAPCC), prioritize energy generation targets but often under-represent biodiversity impacts in project planning and Environmental Impact Assessments (EIAs). EIAs are mandated for large projects, but the scope and enforcement are limited, frequently missing biodiversity-inclusive impact assessments.

- **Lack of cross-sectoral coordination:** India's policies largely operate in silos, with limited integration between the energy and environmental sectors. This lack of cohesive frameworks that jointly address energy production and conservation needs results in unintended biodiversity losses.

- **Minimal focus on restoration or offsetting:** India's renewable energy policies lack clear guidelines on biodiversity offsets or habitat restoration post-project completion, which are essential to mitigate long-term ecological damage.

- **Regulatory inconsistencies:** Hydropower projects often proceed without comprehensive biodiversity assessments, illustrating the ecological risks associated with poorly planned renewable energy projects.

- **Social and political barriers:** There is resistance from communities and industries due to economic concerns, which can hinder the implementation of biodiversity mainstreaming in energy projects.

- **Technical and financial constraints:** Limited capacity and resources to implement biodiversity mainstreaming pose significant challenges to integrating biodiversity considerations into power sector planning and policy.

These gaps underscore the urgent need for policy amendments, best practice guidelines, and collaborative approaches to foster partnerships between government, the private sector, and conservation NGOs to address the biodiversity impacts of the power sector.

5.2. Best practices: propose strategies for responsible siting and development of energy projects, minimizing habitat fragmentation

Several strategic approaches can help minimize biodiversity impacts:

- **Robust EIAs and spatial planning:** Mandate biodiversity-inclusive EIAs and utilize geospatial tools to avoid sensitive habitats. Integrated landscape planning should align energy projects with conservation goals.

- **Ecosystem-based siting:** Projects should avoid high-biodiversity zones, migratory routes, and breeding grounds by applying cross-sectoral data and informed planning.

- **Design and restoration measures:** Incorporate wildlife corridors, green buffers, and post-project restoration. Promote habitat rehabilitation and biodiversity offsets to mitigate ecological damage.

- **Cross-sector collaboration:** Build partnerships among government bodies, private developers, and NGOs. Include community stakeholders in decision-making to address ecological and social priorities.

- **Technological innovation:** Deploy eco-sensitive technologies—e.g., wind-solar hybrids, bat-friendly turbines—to reduce biodiversity disruption.

Table 5: *Case studies illustrating biodiversity integration in energy projects.*

Case Study	Location	Description	Biodiversity integration measures	Relevance to framework components	Citations
Banni Grassland Solar Project	Gujarat, India	Proposed solar project in a sensitive ecosystem relocated after biodiversity assessments.	Use of screening tools; stakeholder engagement with biodiversity boards; relocation to lower-impact site.	Spatial planning; Biodiversity-inclusive EIAs; Stakeholder engagement.	Gasparatos, et al. [7]; Bennun, et al. [6]; Kiesecker, et al. [18].
Wind Energy in Western Ghats	Maharashtra/Karnataka, India	Wind farms affected bird migration routes and endemic species.	Creation of buffer zones and siting guidelines; landscape-level planning.	Ecosystem-based planning; Mitigation strategies; Monitoring.	Santangeli et al. [10]; Rehbein, et al. [13]; Ledec, et al. [24]; Kiesecker, et al. [30].
Hydropower in Eastern Himalayas	Arunachal Pradesh, India	Small hydropower plants fragmented habitats and river ecosystems.	Proposals for fish ladders, ecological flow management, habitat restoration.	River system planning; Impact assessments; Restoration mechanisms.	Khera, et al. [1]; Lange, et al. [14]; Opperman et al. [20].
Solar Projects in Thar Desert	Rajasthan, India	Solar farms disrupted habitats of the Great Indian Bustard.	Siting avoidance; habitat compensation and corridor creation.	Avoidance of sensitive habitats; Compensatory mitigation.	Degen, et al. [4]; Bennun, et al. [6]; Anjanappa [11]; Kiesecker, et al. [30].
Geothermal Development in Protected Areas	Costa Rica	Renewable expansion aligned with biodiversity goals through early integration.	Environmental safeguards; reforestation; PES schemes; habitat monitoring.	Cross-sectoral coordination; Long-term biodiversity monitoring; Economic incentives.	WRI [8]; Hardner, et al. [9]; Bawa, et al. [31]

Renewable Energy and Offsets Policy	Germany	Biodiversity protection is embedded in national energy legislation (EEG).	Mandatory EIAs; restoration offsets; integration of ecological design standards.	Regulatory enforcement; Policy amendments; Biodiversity-inclusive planning.	OECD [3]; Bennun, et al. [6]; Hardner et al. (2015) [9]; Smith, et al. [35].
Wind-Solar Projects in California Desert	USA	Renewable zones designated through conservation-focused land-use planning.	Use of spatial data to avoid critical habitats; stakeholder-driven planning.	Spatial planning tools; Stakeholder collaboration; Wildlife corridor preservation.	Jager, et al. [23]; Cameron, et al. [25]; Smith, et al. [27].
Marine Wind Energy and Bird Protection	United Kingdom	Offshore wind farms developed with avian migration studies and adaptive planning.	Seasonal timing restrictions; monitoring of bird flight paths; marine spatial planning.	Technological innovation; Adaptive management; Long-term monitoring.	Bennun, et al. [6]; Gorman, et al. [34]; Inger, et al. [40].
Wildlife-Sensitive Wind Development	South Africa	Projects in bat-rich zones redesigned after biodiversity assessments.	Acoustic monitoring for bats; turbine curtailment strategies; biodiversity offsets.	Monitoring and enforcement; Biodiversity-inclusive design; Technological solutions.	Rehbein, et al. [14]; Ledec, et al. [24]; Ma, et al. [44].

5.3. Co-Benefits of mainstreaming biodiversity in power sector planning and policy economic value of ecosystem services

Table 6: *Economic and environmental co-benefits.*

Ecosystem Service	Estimated Annual Economic Value	Reference
Carbon Sequestration	USD 5 billion (200 Mt CO_2 at USD 25/t)	OECD [3]; TEEB [5].
Water Purification	INR 5,000–10,000 per ha/year	TEEB [5]; Berry, et al. [21].
Pollination Services	USD 4.5 billion	Gasparatos, et al. [7].
Soil Erosion Control	USD 1,000–2,500 per ha/year	Smith, et al. [27].
Ecotourism (e.g., Western Ghats)	USD 1 billion	Bennun, et al. [6]; OECD [32].

Social benefits

- **Community well-being and health:** Diverse ecosystems contribute to healthier environments, reducing air and water pollution, which lowers healthcare costs and improves overall quality of life.

- **Cultural and ecotourism value:** Biodiversity regions attract ecotourism, generating significant income for local communities and governments, while providing employment and preserving traditional knowledge.

- **Increased resilience to climate change:** Biodiversity-inclusive development supports local communities to adapt to climate change, ensuring long-term social and economic stability.

- **Preservation of traditional knowledge:** Ecotourism and sustainable agriculture promote biodiversity-friendly development, boosting the rural economy while conserving natural landscapes and cultural heritage.

By integrating biodiversity into energy planning, India can achieve its energy goals while safeguarding its rich natural heritage, leading to a power sector that contributes to long-term ecological sustainability and social well-being.

5.4. Implementation challenges

Table 7: *Key implementation challenges and solutions for mainstreaming biodiversity in the power sector.*

Challenge Area	Key issues	Potential solutions
Policy and Regulatory Gaps	Weak enforcement of biodiversity-inclusive energy policies	Amend existing policies to include biodiversity safeguards
	Lack of cohesive cross-sectoral frameworks	Develop integrated frameworks across energy and environment ministries
Technical Constraints	Limited expertise in biodiversity assessments	Capacity building via training programs
	Poor availability of biodiversity data	Use GIS, IBAT, and remote sensing for site screening
	Inadequate monitoring systems	Standardize national guidelines for impact assessments
Financial Constraints	High costs of assessments and restoration	Mobilize blended finance, green bonds, and climate funds
	Limited R&D funding	Introduce PES schemes, tax incentives, and green certifications
	Lack of financial incentives	Establish biodiversity offset mechanisms
Social and Political Barriers	Community and industry resistance due to cost concerns	Communicate long-term co-benefits (e.g., ecosystem services)
	Perceived trade-off with economic growth	Offer economic incentives and fast-track approvals for compliant projects

	Regulatory uncertainty	Engage stakeholders in planning and decision-making
Data and Methodological Gaps	Incomplete or outdated biodiversity data Lack of consistent methods for integrating biodiversity in energy planning	Develop centralized open-access biodiversity databases Encourage collaboration with academic and research institutions Promote adaptive, science-based planning approaches

5.5. Proposed framework for mainstreaming biodiversity considerations into policy and planning

Figure 2: *Framework for integrating biodiversity into India's power sector policy and planning.*

Here is the matrix organized by thematic areas for integrating biodiversity into India's energy policy and planning framework: [Table 8-13]

Table 8: *Thematic area 1: policy and regulatory framework.*

Component	Action	Objective	Expected outcome
Policy Review and Gap Analysis	Conduct a review of NAPCC and other energy-related policies for biodiversity gaps.	Identify and address shortcomings in biodiversity integration into energy policies.	Policy updates with clear biodiversity considerations.
Regulatory Consistency and Enforcement	Ensure all renewable energy projects comply with biodiversity regulations.	Create consistent regulatory mechanisms for biodiversity conservation.	Strong enforcement of biodiversity protection regulations across projects.

Table 9: *Thematic area 2: planning and assessment.*

Component	Action	Objective	Expected outcome
Biodiversity Impact Assessment	Mandate Biodiversity Impact Assessments (BIAs) for all energy projects.	Evaluate and mitigate biodiversity impacts in the project planning phase.	Biodiversity impacts minimized before project initiation.
Biodiversity-Inclusive EIAs	Strengthen the Environmental Impact Assessment (EIA) process with detailed biodiversity studies.	Ensure biodiversity risks are identified and mitigated.	Comprehensive EIAs fully addressing biodiversity risks.
Long-Term Monitoring and Adaptation	Establish systems for ongoing biodiversity monitoring in energy projects.	Track biodiversity impacts and adapts management strategies.	Continuous improvement in biodiversity conservation measures.

Table 10: *Thematic area 3: cross-sectoral coordination and land-use planning.*

Component	Action	Objective	Expected outcome
Cross-Sectoral Coordination	Facilitate collaboration between energy, environment, forestry, and biodiversity sectors.	Create integrated land-use plans balancing energy needs with biodiversity conservation.	Sustainable land-use and energy planning that protects biodiversity.

Table 11: *Thematic area 4: mitigation and compensation.*

Component	Action	Objective	Expected outcome
Compensatory Mechanisms	Implement biodiversity offsets and habitat restoration mandates for energy projects.	Compensate for unavoidable biodiversity losses due to energy infrastructure.	Restoration of ecosystems and maintenance of biodiversity balance.

Table 12: *Thematic area 5: innovation and technology.*

Component	Action	Objective	Expected outcome
Technological Innovation and Biodiversity-Friendly Design	Invest in eco-friendly technologies and infrastructure designs that reduce ecological impacts.	Minimize the biodiversity footprint of energy infrastructure.	Reduced environmental degradation from energy projects.

Table 13: *Thematic area 6: socio-economic and stakeholder integration.*

Component	Action	Objective	Expected outcome
Stakeholder Engagement	Engage with local communities, policymakers, and environmental NGOs.	Ensure energy projects consider social and ecological perspectives for sustainable development.	Socially accepted and ecologically sustainable energy projects.
Economic and Social Co-Benefits Evaluation	Assess the economic value of biodiversity and social benefits from biodiversity-inclusive energy projects.	Strengthen the case for biodiversity-inclusive energy planning.	Enhanced advocacy for mainstreaming biodiversity in energy policies.

6. Conclusion and Recommendations

The research conducted on mainstreaming biodiversity in power sector planning and policy in India has underscored the critical need for biodiversity-inclusive power sector planning. The findings highlight the significant gaps in current energy policies, particularly in the integration of biodiversity considerations into renewable energy projects. The rapid expansion of India's energy sector, driven by the need to meet growing energy demands and climate targets, has led to unintended ecological consequences, including habitat destruction and species displacement. The research emphasizes the urgent necessity to reconcile energy production with biodiversity conservation to ensure sustainable development and the protection of India's rich natural heritage.

7. Policy Recommendations

To address the identified gaps and challenges, the research proposes a comprehensive framework for mainstreaming biodiversity in India's energy policy. This framework includes the following key recommendations:

- **Policy amendments:** Introduce mandatory biodiversity impact assessment guidelines for all energy projects to ensure that potential ecological impacts are thoroughly evaluated and mitigated at the planning stage.

- **Best practice guidelines:** Develop sector-specific recommendations for renewable energy planning that prioritize biodiversity conservation. These guidelines should cover the entire project lifecycle, from site selection to decommissioning, and promote the use of innovative, biodiversity-friendly technologies and practices.

- **Collaborative approaches:** Foster partnerships between government, private sector, and conservation NGOs to leverage the expertise and resources of each stakeholder group. This collaborative approach is essential for the successful implementation of biodiversity mainstreaming initiatives.

- **Spatial planning tools:** Utilize spatial planning tools to identify optimal locations for energy projects that minimize ecological impacts and protect biodiversity hotspots.

- **Ecosystem-based approaches:** Adopt ecosystem-based approaches to energy development that are tailored to local ecological conditions and promote the coexistence of energy infrastructure with natural ecosystems.

- **Community engagement:** Engage local communities in energy planning to enhance the social acceptability of renewable energy projects and ensure that the benefits of biodiversity conservation are shared equitably.

8. Future Research

The research acknowledges that while the proposed framework provides a foundation for integrating biodiversity into India's energy policy, there are areas that require further investigation. Future research should focus on the following:

- **Long-term biodiversity monitoring:** Establish robust systems for long-term biodiversity monitoring in energy projects to assess the effectiveness of mitigation measures and adapt management strategies accordingly.

- **Economic and social co-benefits:** Conduct in-depth analyses of the economic value of biodiversity and the social benefits of biodiversity-inclusive development to strengthen the case for mainstreaming biodiversity in energy planning.

- **Policy and regulatory effectiveness:** Evaluate the effectiveness of existing and proposed policies and regulations to ensure they are achieving their intended outcomes in terms of biodiversity conservation.

By implementing these recommendations and conducting further research, India can advance its energy goals while safeguarding its invaluable biodiversity, thereby ensuring a harmonious coexistence between development and nature.

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