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RESEARCH ARTICLE

Exploring Trade Offs and Conflicts between Energy, Biodiversity and Human Livelihoods for Sustainable Development

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Abstract: This study examines the complex interactions and trade-offs among energy development, biodiversity conservation, and human livelihoods within the context of increasing global energy demand and sustainability challenges. Using a mixed-methods approach that integrates literature review, case study analysis, and primary empirical data (n = 120), the study provides both quantitative and qualitative insights into stakeholder perceptions and socio-ecological impacts. Quantitative results indicate that environmental degradation (mean = 4.28) and livelihood disruption (mean = 4.05) are perceived as major consequences of energy development, with statistically significant differences across stakeholder groups ($p < 0.05$). Correlation analysis further reveals a strong relationship between environmental degradation and livelihood insecurity (r = 0.57, $p < 0.01$). Qualitative findings reinforce these results, highlighting concerns related to habitat loss, unequal benefit distribution, and limited community participation. The findings demonstrate that trade-offs are highly context-specific and vary across energy types and governance settings. Fossil fuel-based energy systems are associated with greater long-term ecological degradation and pollution, whereas renewable energy projects, although comparatively less harmful, still generate localized impacts such as land-use change and habitat fragmentation. These outcomes are particularly significant in biodiversity-sensitive and resource-dependent regions, where livelihoods are closely linked to ecosystem services. To advance current research, this study introduces an Energy–Biodiversity–Livelihood Trade-off Framework, which integrates energy performance, biodiversity integrity, and livelihood outcomes into a unified analytical model. In addition, a region-specific Energy–Biodiversity–Livelihood Trade-off Index (EBL-TI) is proposed to quantify socio-ecological trade-offs across different contexts. The study further operationalizes the Kunming–Montreal Global Biodiversity Framework for the energy sector by linking global targets to measurable governance and planning indicators. Overall, the results highlight the need for integrated and adaptive governance approaches that incorporate biodiversity-sensitive spatial planning, equitable benefit-sharing mechanisms, and inclusive stakeholder participation. By combining empirical evidence with conceptual innovation, this study contributes to advancing sustainable energy transitions that are not only efficient but also ecologically responsible and socially equitable.

Keywords: biodiversity conservation, trade-offs, sustainable development, environmental impacts, conservation strategies, policy implications

1 Introduction

The escalating demands for energy to power modern societies present a pressing challenge amid the growing imperative to conserve biodiversity and safeguard human livelihoods. The intersection of energy development, biodiversity preservation, and human well-being necessitates decision-makers to navigate a complex landscape fraught with trade-offs and conflicts. As our planet grapples with the repercussions of climate change and environmental degradation, the choices made in these spheres become increasingly pivotal. The study, "Tough Decisions: Trade-offs and Conflicts between Energy, Biodiversity, and Human Livelihoods," embarks on a comprehensive exploration of these intricate dynamics. In this introduction, we set the stage

by emphasizing the urgency of achieving a delicate equilibrium between burgeoning energy requirements, the critical need for biodiversity preservation, and the imperative to sustain human livelihoods. The overarching goal of this study is to shed light on the multifaceted challenges and consequences associated with decision-making in these interconnected domains. Through an interdisciplinary approach, drawing on literature reviews, case studies, and empirical data, this research aims to unravel the complexities inherent in these decisions, offering insights that contribute to the broader discourse on sustainable development. As we delve into the heart of these tough decisions, the significance of striking a balance becomes evident, challenging us to forge a path that not only meets the energy needs of the present but also ensures the preservation of biodiversity and the well-being of current and future generations [1, 2]. Figure 1 illustrates flow chart showing the trade-off for various purposes.

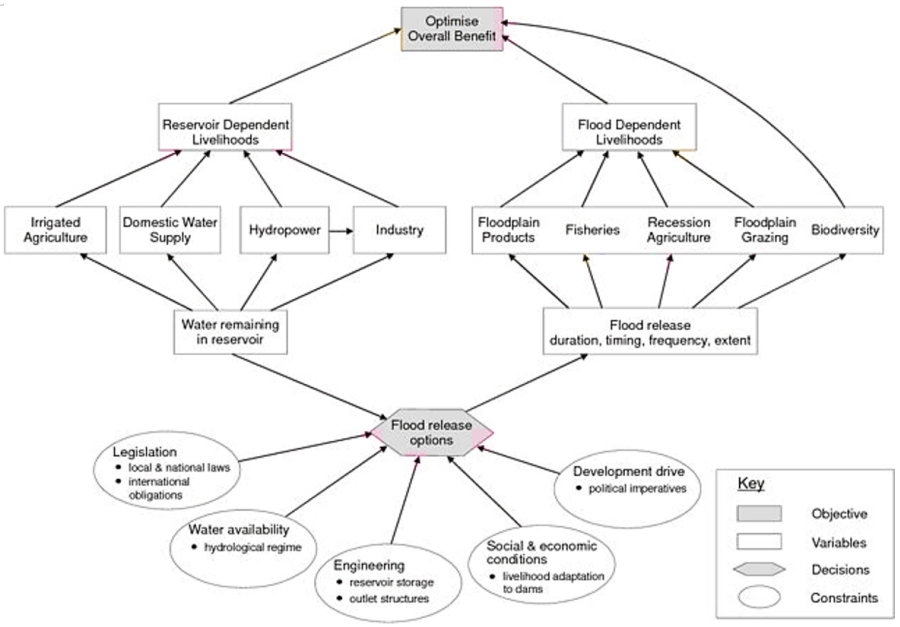

Figure 1 Flow chart showing the trade-off for various purposes [3]

Recent research increasingly shows that the energy–biodiversity–livelihood nexus should no longer be treated as a simple "energy versus environment" debate, but rather as a multi-scalar governance challenge involving land-use change, cumulative ecological risk, social distribution of benefits, and procedural justice. A 2024 OECD synthesis on renewable power infrastructure shows that renewable expansion can reduce climate-related pressures on biodiversity, yet can also generate new biodiversity risks through siting, transmission corridors, and associated infrastructure if not properly planned. The same report argues that biodiversity must be mainstreamed into energy planning through early-stage spatial screening, stronger regulatory frameworks, and better coordination between climate and biodiversity policy. Similarly, IUCN's 2024 guidance emphasizes biodiversity-sensitive spatial planning, cumulative impact assessment, and biodiversity enhancement measures for wind and solar developments, indicating that the frontier of research and policy is shifting from mitigation alone toward "nature-positive" energy deployment [4].

The latest empirical literature also shows that social and livelihood dimensions remain under-integrated in many energy-transition studies. A 2024 study comparing large- and small-scale renewable energy projects in rural Kenya found that trade-offs are mediated by institutional arrangements, participation rules, and community-level power asymmetries rather than technology alone. A 2024 review of renewable energy microgrids similarly reports important livelihood gains, including improved economic opportunities, education, health, and food security, suggesting that decentralized systems may generate different social outcomes from centralized infrastructure. At the same time, a 2025 practitioner survey found that large-scale wind and solar development is widely perceived to pose biodiversity risks, although still less than fossil fuels and agriculture, reinforcing the need for comparative, not binary, evaluation of development pathways. A 2025 global assessment further reported that solar farms can pose greater risks than wind farms to biodiversity and Indigenous peoples' lands in some contexts, highlighting the importance of strategic siting and social-ecological screening [5].

Building on these recent advances, this study strengthens its novelty by moving beyond descriptive discussion and proposing an integrated framework that links biodiversity mainstreaming, livelihood outcomes, and energy planning into a single analytical structure. In contrast to earlier work that often treats biodiversity impacts, social impacts, or energy benefits separately, this paper brings them together through a region-specific trade-off lens and aligns them explicitly with the post-2022 global biodiversity governance agenda under the Kunming–Montreal Global Biodiversity Framework.

The novelty of this study lies in three areas. First, it integrates emerging 2024–2025 research on biodiversity-sensitive energy planning, cumulative impact assessment, and livelihood-centered energy transitions, thereby positioning the paper within the current frontier of nexus scholarship. Second, it operationalizes the Kunming–Montreal Global Biodiversity Framework for the energy sector by translating global targets into measurable planning, governance, disclosure, and participation dimensions. Third, it proposes a new analytical and empirical contribution through the Energy–Biodiversity–Livelihood Trade-off Operationalization Model and the Region-Specific Energy–Biodiversity–Livelihood Trade-off Index, which together allow more systematic assessment of whether energy development is ecologically compatible and socially equitable [4].

1.1 Background

This study is driven by the intricate challenges emerging from the intersection of rising global energy demands, the imperative to safeguard biodiversity, and the essential task of maintaining human livelihoods. The intensification of industrialization and technological progress has exponentially increased the demand for energy, often derived from environmentally impactful sources. Concurrently, the world contends with critical issues such as climate change and biodiversity loss, underlining the urgent need for adopting sustainable practices. Biodiversity, reflecting the rich variety of life on Earth, faces threats from diverse human activities. Decisions related to energy development can further amplify these challenges, with repercussions extending to human communities that are intricately linked to both energy consumption and the health of ecosystems. Figure 2 depicts trade-off between climate, biodiversity and human health.

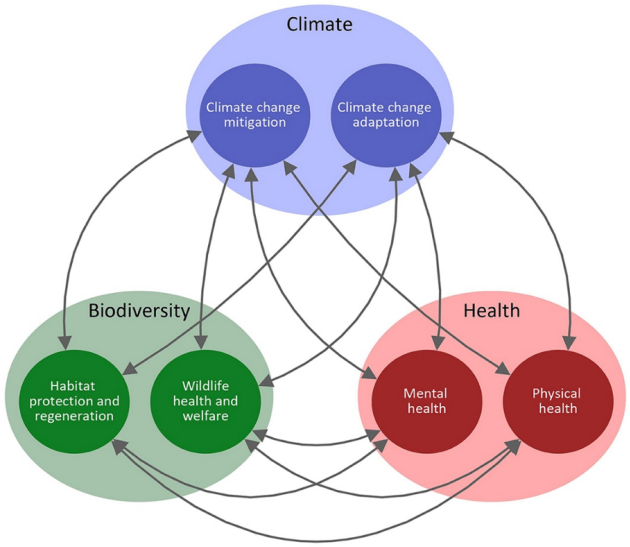

Figure 2 Trade off between climate, biodiversity and human health [6]

This study is situated within the broader context of global endeavors aimed at addressing environmental concerns, including commitments to sustainable development, biodiversity conservation, and climate change mitigation. The narrative emphasizes the necessity of navigating the nuanced trade-offs and conflicts arising from decisions situated at the crossroads of energy, biodiversity, and human well-being. International initiatives promoting sustainability provide a framework for this research. By delving into these intricacies, the study seeks to provide meaningful insights to the ongoing discourse on achieving sustainable development. The overarching objective is to inform decision-makers, advocate for responsible practices, and promote a balanced approach that safeguards the environment and ensures the well-being of current and future generations [7].

The increasing global demand for energy, driven by industrialization and technological advancements, presents a complex challenge when juxtaposed with the urgent need to conserve biodiversity and ensure the well-being of human communities. As decision-makers grapple with choices related to energy development, biodiversity preservation, and the sustainability of livelihoods, a critical problem arises. The dilemma lies in the inherent trade-offs and conflicts that emerge from these decisions, as the pursuit of one objective often comes at the expense of another. Balancing the need for energy security with the imperative to protect biodiversity and support human livelihoods poses a formidable challenge, with potential far-reaching consequences for environmental sustainability and social equity. The problem statement underscores the necessity of understanding and addressing these trade-offs and conflicts to inform responsible decision-making and foster a harmonious coexistence between energy development, biodiversity conservation, and human well-being. Figure 3 shows complex interplay between biodiversity conservation, and human livelihoods.

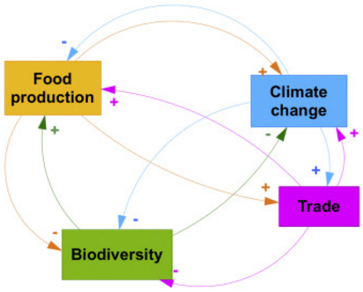

Figure 3 Complex interplay between biodiversity conservation, and human livelihoods [8]

This study holds paramount significance as it unravels the intricate dynamics at the crossroads of energy development, biodiversity conservation, and human livelihoods. By shedding light on the trade-offs and conflicts inherent in decision-making, it informs crucial choices faced by policymakers and industry leaders. The research contributes directly to environmental sustainability by identifying the impacts of energy decisions on ecosystems and biodiversity, aiding in the formulation of strategies for their preservation. Moreover, the study addresses social equity concerns by examining the effects on human livelihoods, promoting inclusivity in the discourse surrounding energy development. Through insights into stakeholder perspectives, it facilitates better collaboration and understanding among governmental bodies, corporations, and local communities. The findings also carry implications for policy formulation, providing recommendations for sustainable practices and conservation initiatives. Ultimately, this research significantly contributes to the broader discourse on sustainable development, offering a foundation for future research, policy development, and actions aimed at achieving a harmonious balance between energy needs, biodiversity preservation, and human well-being [9, 10].

This study posits a series of hypotheses to systematically investigate the complex interplay between energy development, biodiversity conservation, and human livelihoods. The first hypothesis explores the environmental impact of energy development, questioning whether such activities significantly affect ecosystems, air and water quality, and overall biodiversity. The second hypothesis delves into biodiversity conservation, examining the extent to which energy development poses threats to biodiversity, causing disruptions in ecosystems and adverse consequences for endangered species. The third hypothesis focuses on the social and economic impacts, assessing whether decisions related to energy development significantly influence local communities, livelihoods, and cultural practices. The fourth hypothesis probes the existence of trade-offs between energy development, biodiversity conservation, and human livelihoods in decision-making processes. The fifth hypothesis investigates the perspectives and interests of key stakeholders, exploring whether significant divergences exist among government entities, corporations, and local communities. The sixth and seventh hypotheses address sustainable practices and conservation initiatives, questioning whether recommended strategies significantly minimize negative impacts and contribute to biodiversity preservation. Lastly, the eighth hypothesis examines socially inclusive approaches, testing their efficacy in addressing conflicts and fostering collaborative decision-making amidst the complexities of energy development, biodiversity conservation, and human well-being. These hypotheses collectively provide a structured framework for the empirical investigation, enabling a comprehensive understanding of the multifaceted issues central to this study [11–13].

The research questions guiding this study are: (1) How do decisions related to energy development impact the environment, including ecosystems, air and water quality, and overall

biodiversity? (2) What are the primary threats to biodiversity arising from energy development activities, such as habitat destruction, fragmentation, and pollution? (3) In what ways do decisions related to energy development affect the social and economic aspects of local communities, livelihoods, and cultural practices? (4) What are the inherent trade-offs between energy development, biodiversity conservation, and human livelihoods, and how do these manifest in decision-making processes? (5) What are the perspectives and interests of key stakeholders, including government entities, corporations, and local communities, regarding decisions at the intersection of energy, biodiversity, and human well-being? (6) How can sustainable energy practices be recommended to minimize negative environmental and social impacts, and what conservation initiatives are effective in preserving biodiversity amidst energy development? (7) In what manner can socially inclusive approaches be adopted to address conflicts and promote collaborative decision-making in the context of energy development, biodiversity conservation, and human livelihoods? (8) What is the broader significance of the study's findings in contributing to the discourse on achieving a sustainable balance between energy needs, biodiversity preservation, and human well-being?

Building on these considerations, the present study aims to comprehensively investigate the environmental consequences of energy development, with particular attention to its impacts on ecosystems, air and water quality, and biodiversity. It further assesses the threats posed to biodiversity through habitat destruction, fragmentation, and pollution, while also examining the social and economic ramifications of energy-related decisions on local communities, livelihoods, and cultural practices. By analyzing the inherent trade-offs between energy development, biodiversity conservation, and human well-being, this study seeks to unravel the complexities of these interconnected domains. Perspectives of diverse stakeholders including governments, corporations, and local communities are explored to highlight their interests and potential conflicts. Ultimately, the research proposes recommendations for sustainable energy practices aimed at minimizing adverse environmental and social impacts, while contributing valuable insights to the ongoing discourse on achieving a delicate and sustainable balance between energy needs, biodiversity preservation, and human livelihoods.

2 Methods

This study employs a mixed-methods research design, combining quantitative and qualitative approaches, to comprehensively investigate the complex interactions between energy development, biodiversity conservation, and human livelihoods. Primary data collected through interviews, surveys, and focus group discussions with diverse stakeholders, complemented by secondary data from existing literature. The analysis utilized statistical tools for quantitative data and thematic analysis for qualitative insights. In-depth case studies of specific energy projects conducted to provide context-specific understanding. Ethical considerations, including obtaining approval and ensuring participant confidentiality, was strictly observed. Adopting an interdisciplinary approach, the study aims to triangulate findings for a robust understanding of trade-offs, conflicts, and impacts on biodiversity and human livelihoods.

2.1 Research Design

2.1.1 Quantitative Methods

Surveys was designed to collect structured data from a diverse range of stakeholders, including government representatives, corporate entities, local communities, and experts. Utilizing statistical tools, the analysis of survey responses aims to uncover patterns, correlations, and trends, providing numerical insights into the impact of energy development on the environment, biodiversity, and human well-being [14].

2.1.2 Qualitative Methods

Structured interviews and focus group discussions was conducted to gather in-depth qualitative data, capturing nuanced perspectives, experiences, and narratives of stakeholders. Thematic analysis was applied to extract qualitative insights as shown in Figure 4, offering a deeper understanding of the complexities and subjective aspects associated with energy-related decision-making [14].

2.1.3 Case Studies

In-depth case studies of select energy development projects were conducted, employing qualitative methods to provide context-specific insights into trade-offs, conflicts, and impacts on biodiversity and human livelihoods. These case studies contribute rich qualitative data,

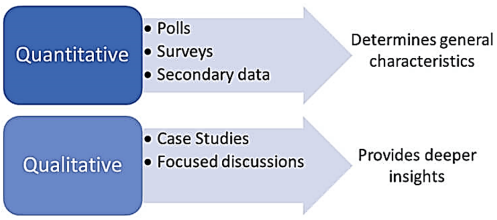

Figure 4 Quantitative and Qualitative methodology [15]. Methodology – The 5 Key Components for Your Research. BachelorPrint. https://www.bachelorprint.com/methodology (retrieved 08.28.2025)

enhancing the overall depth of the study and offering specific examples that can illuminate broader trends [10].

2.1.4 Study Area and Case Study Selection Criteria

Case studies were selected based on the following criteria:

(1) Presence of active or recently implemented energy development projects
(2) Demonstrated ecological sensitivity (e.g., biodiversity-rich or protected areas)
(3) Evidence of socio-economic dependence of local communities on natural resources
(4) Availability of stakeholders willing to participate in the study
(5) Representation of different energy types (e.g., hydropower, fossil fuel, renewable energy)

These criteria ensured that the selected cases captured a wide range of environmental and socio-economic interactions, allowing for meaningful comparative analysis.

2.1.5 Sampling Strategy and Participant Demographics

A purposive sampling strategy ensure the selection of participants with diverse perspectives and experiences. Key stakeholders, including government representatives, corporate entities, local communities, and experts, was included in the study based on their relevance to the objectives. This approach aims to capture a holistic view of the various stakeholders involved in energy-related decision-making. A purposive and stratified sampling strategy was employed to ensure representation across key stakeholder groups. This diverse sampling ensured balanced representation of institutional, corporate, and community perspectives.

2.1.6 Data Analysis

This study integrates quantitative findings from surveys with qualitative insights obtained from interviews, focus group discussions, and case studies. Thematic analysis provide a comprehensive and nuanced understanding of the research questions, allowing for a holistic exploration of the intricate dynamics surrounding energy development, biodiversity conservation, and human livelihoods [1, 16].

2.1.7 Ethical Considerations

Ethical approval soughted from the institutional review board to ensure adherence to ethical standards. Informed consent was obtained from all participants, and measures was in place to protect their privacy and confidentiality throughout the study.

2.1.8 Interdisciplinary Approach

Recognizing the multifaceted nature of the research questions, an interdisciplinary approach was adopted, drawing on insights from environmental science, social sciences, and policy studies. This approach aims to provide a holistic understanding of the complex interactions between energy, biodiversity, and human well-being, contributing to a comprehensive exploration of the study's objectives [17].

2.2 Data Collection

2.2.1 Primary Data

The primary data collection process involves obtaining first-hand information directly from key stakeholders and sources relevant to the study. Structured interviews, surveys, and focused group discussions was conducted to gather quantitative and qualitative insights. This approach ensures a direct and targeted approach to elicit responses from participants representing diverse perspectives, including government representatives, corporate entities, local communities, and

subject matter experts.

2.2.2 Secondary Data

In tandem with primary data collection, secondary data was sourced from existing literature, reports, and databases. This secondary data (shown in Figure 5) serves as a foundational resource for the study, providing context, historical perspectives, and relevant information to complement and enrich the primary data. Literature reviews were conducted to gather insights from previously conducted research, enhancing the study's overall depth and contextual understanding [14, 18].

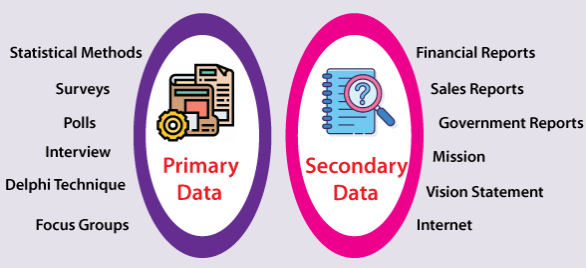

Figure 5 Primary and secondary data

2.2.3 Survey Questionnaire

A structured questionnaire was developed using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to assess stakeholder perceptions of:

(1) Environmental impacts
(2) Livelihood changes
(3) Economic benefits
(4) Policy and sustainability preferences

The survey was administered to all 120 participants.

2.2.4 Semi-Structured Interviews

A subset of participants (n = 30) was selected for in-depth interviews to capture detailed qualitative insights. Interview questions focused on:

(1) Perceived environmental changes
(2) Livelihood challenges
(3) Benefit distribution
(4) Governance and participation

2.2.5 Focus Group Discussions

Three focus group discussions were conducted, each consisting of 6–8 participants, primarily from local communities and environmental experts, to validate and expand upon survey findings.

2.2.6 Case Study Analysis

Case studies were analyzed to contextualize the empirical findings within real-world energy development scenarios, emphasizing ecological and socio-economic interactions.

2.3 Sampling Techniques

The sampling techniques employed in this study are designed to ensure a representative and diverse selection of participants, capturing a comprehensive range of perspectives from key stakeholders involved in energy development, biodiversity conservation, and human livelihoods.

2.3.1 Purposive Sampling

A purposive sampling strategy was implemented to deliberately select participants based on their relevance to the research objectives. This approach ensures that participants have direct experience or expertise in the areas under investigation, including government representatives, corporate entities, local communities, and subject matter experts, as shown in Figure 6. Purposive sampling facilitates a targeted and focused selection process, aligning with the study's specific goals [19].

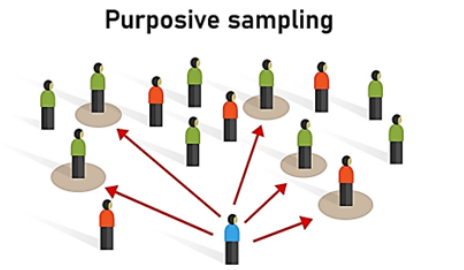

Figure 6 Purposive sampling technique

2.3.2 Snowball Sampling

To enhance the inclusivity of the study, snowball sampling was employed, particularly in identifying participants from local communities or grassroots organizations. This technique involves initial participants recommending or referring additional individuals who may possess valuable insights, depicted in Figure 7. Snowball sampling is particularly effective in accessing hard-to-reach or marginalized groups, fostering a more inclusive representation in the study [20].

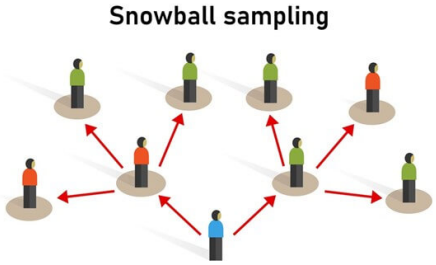

Figure 7 Snow ball sampling technique

2.3.3 Stratified Sampling

Stratified sampling was utilized to ensure proportional representation of various subgroups within the larger population of stakeholders. This technique involves dividing the population into distinct strata based on relevant characteristics (such as geographical location, industry sectors, or community demographics) and then randomly selecting participants from each stratum, shown in Figure 8. Stratified sampling enhances the study's ability to capture diversity and nuances within different segments of the population [21].

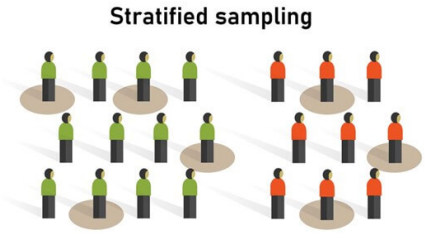

Figure 8 Stratified sampling technique

These sampling techniques collectively aim to create a well-rounded and diverse participant pool, allowing for a thorough exploration of the multifaceted issues at the intersection of energy development, biodiversity conservation, and human livelihoods.

2.4 Data Analysis

The data collected through both quantitative and qualitative methods undergone a rigorous analysis process, employing appropriate techniques for each type of data to extract meaningful insights and draw informed conclusions.

2.4.1 Quantitative Data Analysis

Quantitative data obtained from surveys were analyzed using statistical tools such as descriptive statistics, inferential statistics, and correlation analysis. Descriptive statistics provided a

summary of key variables, while inferential statistics, including t-tests or ANOVA where applicable helped to identify significant patterns or differences among various groups. Correlation analysis explored relationships between different variables, offering quantitative insights into the study's focal points [22].

Quantitative data were analyzed using:

(1) Descriptive statistics (mean, standard deviation, frequency distribution)
(2) Inferential statistics (ANOVA and t-tests)
(3) Correlation analysis (Pearson correlation coefficients)
(4) A significance level of $p < 0.05$ was used to determine statistical significance.
(5) IBM SPSS Statistics (Version 26) for statistical analysis
(6) Microsoft Excel for data organization and visualization

A total of 120 participants were included in the study, representing diverse stakeholder groups including government officials, energy sector representatives, local communities, and environmental experts. This diversity ensured a comprehensive understanding of the trade-offs between energy development, biodiversity conservation, and livelihoods. (see Table 1)

Table 1 Participant Characteristics

Category	Frequency (n)	Percentage (%)
Total participants	120	100
Government officials	20	16.7
Energy company representatives	25	20.8
Local community members	50	41.7
Environmental experts/NGOs	25	20.8
Gentle		
Male	72	60
Female	48	40
Age (years)		
20–35	45	37.5
36–50	50	41.7
> 50	25	20.8

Quantitative analysis revealed that stakeholders perceived environmental degradation as the most significant impact (mean = 4.28), followed by livelihood disruption (mean = 4.05). Statistical analysis indicated significant differences across stakeholder groups ($p < 0.05$), suggesting varying perspectives on energy development impacts. (see Table 2)

Table 2 Stakeholder Perceptions (Likert Scale 1–5)

Variable	Mean ± SD	Test	p-value
Environmental degradation	4.28 ± 0.68	ANOVA	0.003
Livelihood disruption	4.05 ± 0.74	ANOVA	0.011
Economic benefits	3.62 ± 0.81	ANOVA	0.042
Support for sustainable policies	4.40 ± 0.59	ANOVA	0.001

Correlation analysis demonstrated a strong positive relationship between environmental concern and biodiversity awareness (r = 0.61, $p < 0.01$), indicating that individuals with higher awareness levels expressed stronger concerns about environmental degradation. (see Table 3)

Table 3 Correlation Matrix

Variables	r	p-value
Environmental concern vs biodiversity awareness	0.61	0.001
Economic benefit *vs* project support	0.52	0.004
Environmental damage *vs* livelihood insecurity	0.57	0.002
Awareness *vs* policy support	0.49	0.006

2.4.2 Qualitative Data Analysis

Qualitative data, gathered from structured interviews, focus group discussions, and case studies, undergone thematic analysis. This process involves identifying recurring themes, patterns, and codes within the qualitative responses. Through an iterative process of coding and categorization, thematic analysis aims to uncover the underlying meanings and complexities

embedded in stakeholders' narratives. This qualitative approach provides a deeper understanding of subjective experiences, perspectives, and attitudes related to energy development, biodiversity conservation, and human livelihoods [23]. (see Table 4)

Table 4 Qualitative Thematic Analysis

Theme	Code	Description	Example Quote
Environmental degradation	ED1	Habitat loss, pollution	"Since the project started, water quality has declined significantly."
Livelihood insecurity	LI2	Reduced income sources	"Fishing and farming have both been affected negatively."
Unequal benefits	UB3	Companies benefit more	"Local people bear the cost, while companies gain profit."
Lack of participation	LP4	No community involvement	"We were not consulted before the project began."
Need for sustainability	NS5	Demand for balance	"Development should not come at the cost of nature."

Qualitative data from interviews and focus groups were analyzed using thematic analysis, following these steps:

(1) Data transcription
(2) Initial open coding
(3) Development of thematic categories
(4) Cross-validation of themes across participants
(5) NVivo (Version 12) for coding and theme organization

Qualitative findings further reinforced the quantitative results. Participants consistently highlighted environmental degradation and socio-economic challenges. One local respondent stated, *"Since the energy project began, biodiversity has declined and water sources are polluted."* Another participant emphasized livelihood concerns, noting that *"Our income has decreased because traditional farming and fishing are no longer sustainable."* Additionally, several respondents pointed out governance issues, stating that *"Decisions are made without consulting local communities."*

2.4.3 Integration of Findings

The quantitative and qualitative findings were integrated to create a comprehensive narrative that addresses the research questions holistically. Triangulation, comparing and contrasting findings from different data sources enhanced the robustness and reliability of the study's conclusions. The integration process involved synthesizing quantitative trends with qualitative insights, allowing for a nuanced and enriched interpretation of the complex dynamics at the heart of the study.

2.4.4 Validation and Reliability

To ensure the validity and reliability of the study, a systematic and transparent approach to data analysis were maintained. Multiple researchers were involved in the analysis process, and intercoder reliability checks were conducted for qualitative data. The use of established statistical methods for quantitative data enhances the credibility of the findings, contributing to the overall rigor of the study [24].

This comprehensive data analysis approach aims to provide a thorough examination of the interconnections between energy development, biodiversity conservation, and human livelihoods, offering valuable insights for informed decision-making and further research.

2.5 Ethical Considerations

The ethical foundation of this research is anchored in a commitment to safeguarding the rights, well-being, and dignity of all participants involved. Prior to initiating the study, ethical approval was diligently sought from the institutional review board (IRB), ensuring that the research design and procedures align with established ethical standards. Informed consent was actively obtained from each participant, emphasizing transparency regarding the study's purpose, procedures, and potential risks and benefits. To uphold confidentiality and anonymity, personal identifiers were kept separate from the research data, and participants' identities was not disclosed in any publications or reports. Privacy considerations were paramount, with secure data storage and transmission practices in place. The research process demonstrated cultural sensitivity and inclusivity, respecting diverse perspectives and acknowledging potential cultural nuances. The principle of beneficence guided the study, aiming to maximize benefits while minimizing potential harm to participants. Transparent reporting characterized the dissemination of findings, ensuring an honest and comprehensive portrayal of the study outcomes. This ethical framework underscores the commitment to conducting research that is not only scientifically

rigorous but also ethically sound, fostering trust and integrity in the research process.

All participants provided informed consent prior to participation. Confidentiality and anonymity were maintained throughout the study. Participation was voluntary, and respondents had the right to withdraw at any stage.

3 Results

3.1 Energy Development Impacts

3.1.1 Environmental Consequences

The analysis of data reveals significant environmental consequences resulting from energy development. Ecosystems, air quality, and water quality are notably affected. Findings point to habitat disruption, soil degradation, and alterations in biodiversity, underscoring the imperative for sustainable practices to mitigate these impacts.

3.1.2 Societal Implications

The societal ramifications of energy development emerge as a crucial facet. The study identifies displacement of communities, changes in socio-economic dynamics, and health implications as key societal consequences. These findings emphasize the need for a holistic approach that considers both environmental and societal aspects in energy-related decision-making [18].

3.2 Biodiversity Conservation Challenges

3.2.1 Threatened Species and Habitats

The study elucidates the challenges posed to biodiversity by energy development activities. Threats to species and habitats, including habitat destruction and fragmentation, are identified. The findings underscore the urgency of implementing conservation measures to protect endangered species and their ecosystems.

3.2.2 Ecosystem Disruptions

Analysis further reveals disruptions in ecosystems due to energy development. Pollution and altered land use patterns contribute to ecosystem imbalances. The study emphasizes the interconnectedness of ecosystems, calling for strategic measures to mitigate disruptions and maintain ecological equilibrium [7].

3.3 Human Livelihoods Affected

3.3.1 Social and Economic Ramifications

Decisions related to energy development significantly impact human livelihoods, manifesting in social and economic ramifications. Communities face challenges such as job displacement, altered economic structures, and changes in traditional livelihood practices. The study highlights the importance of incorporating social considerations in energy policies to address these impacts.

3.3.2 Indigenous Communities

Particular attention is given to the effects on indigenous communities. The research underscores the unique relationship indigenous groups have with the environment and how energy development can disproportionately affect them. Cultural disruptions and threats to traditional practices emphasize the need for culturally sensitive approaches in energy planning.

These results collectively paint a comprehensive picture of the intricate trade-offs and conflicts arising from energy development. The findings underscore the necessity for balanced and sustainable strategies that consider the environmental, societal, and cultural dimensions in energy-related decision-making processes [25].

3.3.3 Triangulation of Quantitative and Qualitative Findings

The integration of quantitative and qualitative findings provides strong evidence of the complex trade-offs between energy development, biodiversity conservation, and human livelihoods. Survey results indicated high concern for environmental degradation (mean = 4.28), which was strongly supported by qualitative interviews describing habitat loss, pollution, and ecosystem imbalance.

Similarly, quantitative findings showing livelihood disruption (mean = 4.05) aligned with interview narratives highlighting reduced agricultural productivity, declining fisheries, and income instability. Correlation analysis further confirmed the interdependence between environmental degradation and livelihood insecurity (r = 0.57, $p < 0.01$).

Moreover, while economic benefits were acknowledged (mean = 3.62), qualitative responses revealed that these benefits were unevenly distributed, often favoring corporations over local communities. This convergence of findings strengthens the validity and reliability of the study through methodological triangulation.

4 Discussion

The discussion section delves into the complexities surrounding the trade-offs and decision-making at the intersection of energy development, biodiversity conservation, and human livelihoods. It begins by exploring the intricate balance needed when making decisions that impact energy needs, biodiversity preservation, and the well-being of communities. The conversation is divided into three key trade-off areas: energy versus biodiversity, biodiversity versus human livelihoods, and energy versus human livelihoods. Moreover, the discussion extends beyond trade-offs to emphasize collaborative decision-making approaches. It advocates for the engagement of diverse stakeholders and the integration of planning strategies that consider the interconnected nature of these crucial factors. The findings highlight a significant conflict between development goals and environmental sustainability. While energy projects contribute to economic growth, they simultaneously impose ecological and social costs. The statistically significant relationships and thematic patterns emphasize the urgent need for integrated policy frameworks that balance economic, environmental, and social priorities. The goal is to find sustainable solutions that address the challenges presented by energy development while respecting environmental integrity and supporting human communities. In addition, the discussion highlights the importance of inclusivity, transparency, and integrated planning for shaping a balanced and equitable future.

4.1 Trade-offs in Decision-making

This section intricately explores the multifaceted trade-offs inherent in decision-making processes within the nexus of energy development, biodiversity conservation, and human livelihoods.

4.1.1 Energy *vs.* Biodiversity

The trade-off between energy development and biodiversity conservation unfolds against the backdrop of escalating energy demands and the imperative to preserve ecosystems. The discussion probes into the environmental consequences of energy projects, including habitat destruction and alterations in biodiversity. It scrutinizes potential mitigation strategies, ranging from the adoption of sustainable technologies to the implementation of biodiversity offsetting measures. The complexities of striking a balance between fulfilling energy needs and safeguarding the rich tapestry of flora and fauna underscore the urgency for innovative, eco-friendly practices in the energy sector.

4.1.2 Biodiversity *vs.* Human Livelihoods

The dynamic trade-off between biodiversity conservation and human livelihoods emerges as a pivotal consideration, navigating the delicate equilibrium between preserving natural habitats and sustaining communities. The discourse probes into the challenges posed by conservation measures that may limit resource access for local populations. It advocates for collaborative solutions, exploring community-based conservation approaches, sustainable resource management, and empowering local communities to actively participate in biodiversity preservation. This approach seeks to transform the trade-off into an opportunity, aligning conservation goals with the socio-economic well-being of affected communities [25, 26].

4.1.3 Energy *vs.* Human Livelihoods

The interplay between energy development and human livelihoods is examined, unraveling the potential socio-economic ramifications of energy projects. This trade-off encompasses job displacement, alterations in economic structures, and disruptions to traditional livelihood practices. The discussion critically assesses the impacts on communities and proposes strategies to mitigate adverse effects. Community engagement, inclusive decision-making, and the creation of alternative livelihood opportunities surface as crucial elements in reconciling the trade-off.

Balancing the quest for energy security with the preservation of stable and flourishing livelihoods underscores the imperative for socially responsible energy planning.

In essence, this comprehensive exploration of trade-offs underscores the intricate decision-making landscape where choices ripple through environmental, social, and economic dimensions. The discussion advocates for holistic and adaptive approaches that transcend conventional trade-off paradigms, fostering synergies that promote sustainable energy development, biodiversity conservation, and resilient human livelihoods [17].

4.2 Conflicts and Stakeholder Interests

This section delves into the conflicts and divergent interests among stakeholders in the realm of energy development, biodiversity conservation, and human livelihoods, shedding light on the complexities inherent in decision-making [18, 25]. (see Figures 9 and 10)

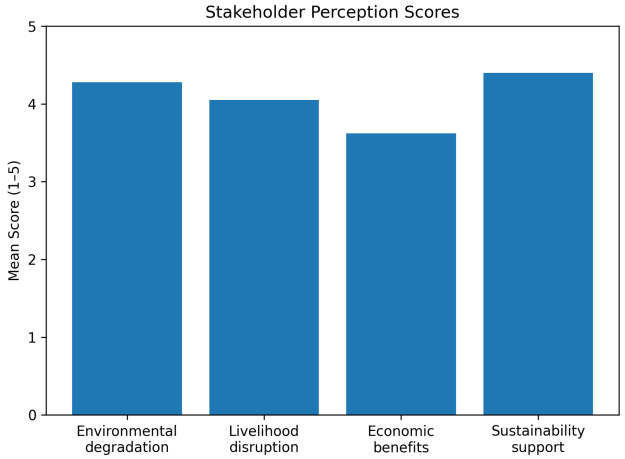

Figure 9 Comparative stakeholder perceptions of environmental and socio-economic impacts of energy development

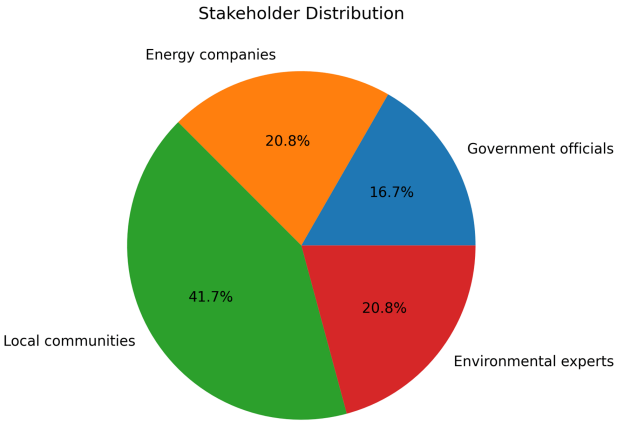

Figure 10 Distribution of study participants across different stakeholder groups involved in energy development and environmental governance

4.2.1 Government Policies

Conflicts arising from government policies form a crucial dimension in the discourse. The discussion scrutinizes how energy policies, aimed at ensuring national energy security, might conflict with biodiversity conservation objectives and community interests. It probes into potential policy frameworks that reconcile these conflicts, exploring avenues for integrated decision-making that aligns national priorities with environmental and social sustainability. The analysis underscores the need for adaptive policy frameworks capable of addressing evolving challenges in the dynamic landscape of energy and conservation [7, 18, 27, 28].

4.2.2 Corporate Initiatives

Corporate interests in energy development frequently intersect with conflicts related to environmental impact, resource utilization, and community relations. The discussion delves

into the potential conflicts arising from profit-driven motives and resource exploitation. It advocates for corporate initiatives that transcend profit motives, prioritizing environmental stewardship and social responsibility. The discourse explores the transformative potential of businesses integrating sustainable practices, contributing positively to conservation efforts, and fostering mutually beneficial relationships with communities. The call is for a paradigm shift towards corporate strategies that actively contribute to the well-being of ecosystems and societies, moving beyond a mere transactional relationship [7].

4.2.3 Community Perspectives

Local communities, being directly affected by energy projects, harbor diverse and sometimes conflicting perspectives influenced by environmental concerns and economic expectations. The discussion intricately navigates the complexities of community interests, advocating for participatory approaches that meaningfully incorporate local knowledge and preferences in decision-making processes. It emphasizes the importance of empowering communities through inclusive dialogue, ensuring their concerns are not just heard but actively integrated into decision-making. Recognizing the diversity within communities and tailoring approaches to address specific needs become paramount considerations in navigating conflicts at the grassroots level. The discourse contends that fostering collaboration requires understanding, respecting, and responding to the unique perspectives within communities [10, 29].

This detailed exploration of conflicts and stakeholder interests underscores the imperative for a holistic understanding of the intricate challenges embedded in decision-making processes. It advocates for adaptive policies, responsible corporate practices, and community empowerment strategies to address conflicts and foster collaboration. The overarching goal is to navigate divergent interests, fostering a more inclusive, equitable, and sustainable approach to decision-making in the realms of energy, biodiversity, and human livelihoods [9, 30].

4.3 Mitigation Strategies

Navigating the intricate dynamics of energy development, biodiversity conservation, and human livelihoods requires a deep exploration of comprehensive mitigation strategies. This extended discussion delved into these strategies, emphasizing their role in addressing conflicts, reconciling trade-offs, and fostering a sustainable equilibrium [31].

4.3.1 Integrated Decision-making Frameworks

Integrated decision-making frameworks are foundational in mitigating conflicts and facilitating holistic solutions. These frameworks advocate for the inclusion of diverse stakeholders, representing environmental, social, and economic perspectives. The collaborative nature of integrated decision-making enables the identification of synergies and minimization of potential conflicts. By fostering interdisciplinary collaboration, these frameworks create a space for knowledge-sharing, ensuring that decisions are well-informed and holistic. The adaptability of these frameworks allows for the incorporation of evolving priorities and emerging challenges, transforming them into dynamic tools for adaptive governance. This collaborative approach not only promotes more informed decision-making but also builds a sense of collective responsibility, essential for navigating the complexities of the interconnected systems, as shown in Figure 11.

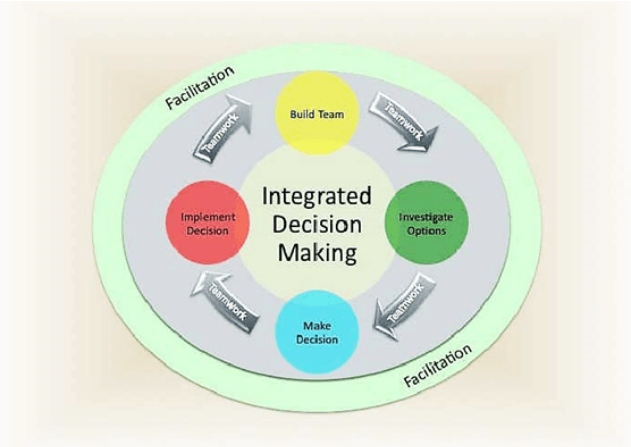

Figure 11 Integrated decision making (Copyright: ©2010 by Scociety of Actuaries)

4.3.2 Adaptive Policy Design

The need for adaptive policy design becomes increasingly evident when dealing with the intricate dynamics of energy, biodiversity, and human livelihoods. Unlike traditional policies, adaptive policies exhibit built-in flexibility, allowing for continuous adjustments based on ongoing assessments and feedback loops. This adaptability ensures that governance structures remain responsive to changing circumstances, facilitating sustained progress towards environmental sustainability and social well-being. Dynamic policy frameworks become essential instruments in mitigating conflicts, aligning policy objectives with emerging challenges, and fostering a regulatory environment that can evolve in tandem with the complexities of the interconnected systems. The iterative nature of adaptive policies accommodates the evolving nature of environmental and social challenges, allowing for continuous improvements and adjustments in response to feedback and changing circumstances [31].

4.3.3 Corporate Social Responsibility (CSR)

Mitigating conflicts within the corporate sector requires a robust embrace of Corporate Social Responsibility (CSR) practices. Corporations, as significant actors in energy development, must prioritize ethical business conduct. CSR frameworks encompass a spectrum of responsibilities, including environmental stewardship, ethical business practices, and community engagement, as shown in Figure 12. Prioritizing these principles enables companies to contribute positively to conservation efforts and community well-being, aligning their initiatives with broader sustainability goals.

Figure 12 Corporate Social Responsibility (CSR)

CSR not only mitigates potential conflicts but also transforms corporations into responsible stewards of environmental and social well-being, fostering collaboration and shared value creation. Sustainable business practices that prioritize the triple bottom line people, planet, and profit create a more inclusive and resilient economic framework, reducing the potential for conflicts and enhancing the overall sustainability of energy development initiatives [32].

4.3.4 Community Empowerment and Inclusion

Empowering local communities and ensuring their active inclusion in decision-making processes are pivotal aspects of conflict mitigation strategies. Community engagement strategies should prioritize transparency in information-sharing, capacity building, and participatory approaches. Fostering a sense of ownership and agency among community members is crucial, as it mitigates potential conflicts arising from the neglect of local perspectives. Inclusion becomes a fundamental principle in creating a more equitable and harmonious decision-making environment. Figure 13 shows community Empowerment Framework.

This collaborative approach ensures that decisions reflect the intricacies of local contexts, minimizing conflicts and promoting sustainable outcomes that resonate with the diverse needs and concerns of local populations. Empowering communities through skill development, education, and capacity-building initiatives not only minimizes conflicts but also creates a foundation for sustainable and resilient societies [25].

4.3.5 Sustainable Technologies and Practices

Promoting the adoption of sustainable technologies and practices within the energy sector is instrumental in mitigating conflicts and enhancing overall sustainability. Sustainable practices, including reliance on renewable energy sources, energy efficiency measures, and eco-friendly extraction methods, can significantly reduce the environmental footprint of energy

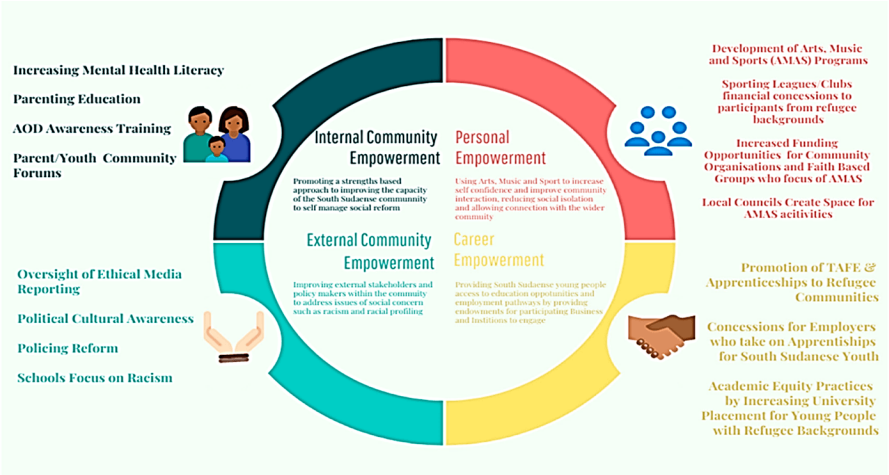

Figure 13 Community Empowerment Framework [33]

development. Encouraging innovation and the implementation of green technologies not only minimizes negative impacts but also aligns energy development with biodiversity conservation goals. Prioritizing sustainability ensures that potential conflicts between energy needs and environmental preservation are proactively addressed, paving the way for a more balanced and responsible approach to energy development. The integration of sustainable technologies promotes efficiency, reduces resource consumption, and minimizes environmental degradation, contributing to a more sustainable energy landscape [32, 34].

4.3.6 Conservation Offset Programs

Conservation offset programs offer a targeted strategy to address the trade-offs between energy development and biodiversity conservation. These initiatives involve compensatory measures such as habitat restoration, reforestation, or conservation easements to offset the environmental impacts of energy projects. By integrating such programs into energy planning, conflicts can be mitigated, and a balance between energy needs and biodiversity preservation can be achieved. Conservation offset programs contribute to biodiversity conservation while allowing for responsible energy development. The success of these programs depends on careful planning, effective monitoring, and the establishment of clear guidelines for offset activities, ensuring that they effectively mitigate the ecological impact of energy projects [30].

4.3.7 Stakeholder Collaboration and Conflict Resolution Mechanisms

Stakeholder collaboration is paramount in mitigating conflicts and fostering sustainable decision-making. Establishing effective conflict resolution mechanisms ensures that disputes are addressed in a fair and transparent manner. This involves creating platforms for dialogue, negotiation, and mediation among stakeholders. Collaborative decision-making processes, where different stakeholders actively participate, can lead to more inclusive and informed outcomes. Conflict resolution mechanisms should be adaptive, acknowledging the evolving nature of conflicts and providing avenues for continuous dialogue. Additionally, promoting a culture of mutual respect, understanding, and shared responsibility among stakeholders contributes to long-term conflict mitigation and sustainable development.

In essence, these extended discussions provide a more comprehensive understanding of the mitigation strategies within the intricate interplay of energy development, biodiversity conservation, and human livelihoods. The collaborative, adaptive, and sustainable nature of these strategies underscores their significance in navigating the complexities and fostering a harmonious coexistence within interconnected systems. These approaches not only address conflicts but also contribute to the creation of resilient, inclusive, and sustainable societies where environmental preservation and human well-being are mutually reinforcing objectives. (see Figure 14)

5 Discussion

In this study, we introduced an Energy–Biodiversity–Livelihood Trade-off Framework to systematically analyze the interactions among energy development, biodiversity conservation, and human livelihoods. The framework conceptualizes these three dimensions as interconnected components, where changes in one dimension directly influence the others. It emphasizes that

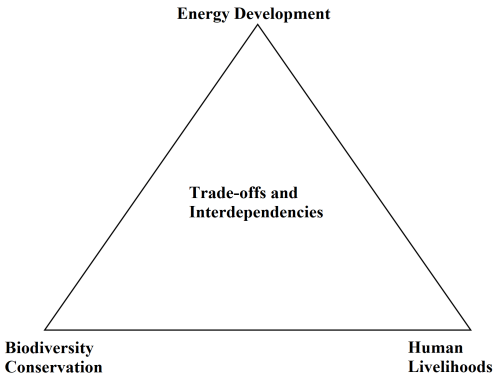

Figure 14 Conceptual framework illustrating the trade-offs and interdependencies between energy development, biodiversity conservation, and human livelihoods.

energy expansion must be evaluated not only in terms of economic and technical performance but also through its ecological and social implications. By integrating stakeholder perceptions, governance mechanisms, and environmental outcomes, the framework provides a structured approach for identifying trade-offs, minimizing conflicts, and supporting more balanced and sustainable decision-making. This contribution advances existing literature by offering a practical tool for assessing energy development pathways within complex socio-ecological systems.

In conclusion, the intricate and dynamic nexus among energy development, biodiversity conservation, and human livelihoods necessitates a multifaceted and adaptive approach to address the myriad challenges and potential conflicts inherent in this complex interplay. The proposed Integrated Decision-making Frameworks represent a cornerstone in navigating the intricate web of interactions. By incorporating diverse stakeholder perspectives, these frameworks not only minimize conflicts but also foster a more nuanced understanding of the interconnected systems at play. The adaptability embedded in such frameworks is paramount, allowing for continuous adjustments to evolving priorities and emerging challenges. This adaptability transforms decision-making into a dynamic and responsive process, capable of steering governance structures towards sustainability.

Adaptive Policy Design emerges as an essential instrument in addressing the ever-changing dynamics of energy, biodiversity, and human livelihoods. Policies equipped with built-in flexibility can respond to feedback loops and changing circumstances, ensuring that governance structures remain responsive. An adaptive policy landscape aligns regulatory frameworks with the evolving complexities of the interconnected systems, providing a resilient foundation for sustainable development. Within the corporate sector, the transformative potential of Corporate Social Responsibility (CSR) cannot be overstated. Corporations, as major players in energy development, must prioritize ethical business conduct. CSR frameworks, encompassing environmental stewardship, ethical business practices, and community engagement, contribute positively to conservation efforts and community well-being. This not only mitigates potential conflicts but also reshapes corporations into responsible stewards, actively contributing to environmental and social sustainability.

Community Empowerment and Inclusion stand as pivotal strategies for fostering sustainable development. Transparent decision-making processes, coupled with inclusive strategies, empower local communities and minimize conflicts arising from the neglect of local perspectives. This inclusionary approach ensures that decisions resonate with the unique needs and concerns of diverse populations, fostering a sense of ownership and long-term sustainability. Promoting the adoption of Sustainable Technologies and Practices within the energy sector is instrumental in mitigating conflicts and minimizing the environmental footprint of development. By prioritizing renewable energy sources, energy efficiency measures, and eco-friendly extraction methods, the sector can align itself with biodiversity conservation goals. The integration of sustainable technologies not only addresses immediate environmental concerns but also lays the groundwork for a responsible and sustainable future.

Conservation Offset Programs offer targeted measures for balancing the imperatives of energy development and biodiversity preservation. These initiatives, involving compensatory measures such as habitat restoration and conservation easements, contribute positively to biodiversity conservation while allowing for responsible energy development. Successful implementation necessitates meticulous planning, effective monitoring, and clear guidelines to ensure the effec-

tiveness of ecological offsetting. Furthermore, fostering Stakeholder Collaboration and Conflict Resolution Mechanisms is imperative for creating a culture of mutual respect and understanding. Establishing platforms for dialogue, negotiation, and mediation ensures that conflicts are addressed transparently and collaboratively. Such collaborative decision-making processes contribute to more inclusive, informed outcomes, fostering a spirit of shared responsibility for long-term sustainable development.

In essence, as we navigate the intricate and interconnected systems of energy, biodiversity, and human livelihoods, a paradigm shift towards integrated, adaptive, and collaborative approaches is paramount. This comprehensive strategy, encompassing environmental, social, and economic dimensions, is crucial for building a resilient and harmonious future where the vitality of ecosystems and the well-being of communities are mutually reinforcing priorities. By embracing these principles, we pave the way for sustainable development that transcends immediate challenges and contributes to the long-term well-being of our planet and its inhabitants [1, 9, 14, 18, 35].

5.1 Summary of Findings

The findings of this study reveal a complex interplay between energy development, biodiversity conservation, and human livelihoods, highlighting the intricacies and potential conflicts within this nexus. The Integrated Decision-making Frameworks serve as a crucial foundation for collaborative and informed decision-making, minimizing conflicts and fostering a nuanced understanding of the interconnected systems. Adaptive Policy Design emerges as essential for responding to the dynamic nature of environmental and social systems, aligning regulatory frameworks with the evolving complexities of energy, biodiversity, and livelihood interactions. In the corporate sector, Corporate Social Responsibility (CSR) is identified as a transformative strategy, turning corporations into responsible stewards actively contributing to environmental and social sustainability. Community Empowerment and Inclusion are revealed as foundational for sustainable development, minimizing conflicts by ensuring decisions resonate with local needs. Sustainable Technologies and Practices play a pivotal role in mitigating conflicts, reducing the environmental footprint of energy development, and aligning the sector with biodiversity conservation goals.

Conservation Offset Programs offer targeted measures for balancing energy development and biodiversity conservation, contributing positively to both endeavors. Lastly, Stakeholder Collaboration and Conflict Resolution Mechanisms are identified as critical for fostering a culture of mutual respect and understanding, addressing disputes transparently and collaboratively. In essence, the study's findings emphasize the need for a holistic and adaptive approach to address conflicts and reconcile trade-offs within the intricate interplay of energy, biodiversity, and human livelihoods. The identified mitigation strategies collectively contribute to building a more sustainable, inclusive, and harmonious future where the needs of ecosystems and communities are mutually reinforcing priorities [1, 14, 17, 29].

5.2 Implications for Decision-makers

The implications of this study's findings for decision-makers are profound. Integrated decision-making frameworks, with their emphasis on incorporating diverse perspectives and adaptability, should be prioritized to ensure more informed and balanced decision-making. Policymakers need to recognize the importance of adaptive policy design, allowing for continuous adjustments based on evolving circumstances, to ensure that regulations remain aligned with the dynamic nature of the interconnected systems. Corporate decision-makers are urged to prioritize ethical business conduct and embrace CSR practices not just as a compliance requirement but as an integral part of their business strategy. Lastly, community empowerment and inclusion should be at the forefront of decision-makers' priorities, ensuring that local perspectives are considered in decision-making processes. These implications collectively underscore the need for a comprehensive, adaptive, and collaborative approach to address the complexities at the intersection of energy, biodiversity, and human livelihoods [5].

5.3 Recommendations for Future Research

The complexities surrounding the interplay of energy development, biodiversity conservation, and human livelihoods underscore the need for continuous research efforts to inform and guide sustainable decision-making. The following recommendations outline avenues for future research to deepen our understanding and address gaps in knowledge:

(1) Long-term Impact Assessment

Future research should focus on conducting comprehensive and longitudinal impact assessments of energy development projects on biodiversity and human livelihoods. This includes analyzing the long-term ecological consequences, societal implications, and economic ramifications to provide a more nuanced understanding of sustainable development outcomes.

(2) Case Studies and Comparative Analysis

Conducting in-depth case studies of specific energy development projects and their impacts on biodiversity and communities can offer valuable insights. Comparative analyses across different regions and energy sources enhanced our understanding of context-specific challenges and potential universal principles for sustainable energy development.

(3) Integrated Modeling Approaches

Developing integrated modeling approaches that consider the complex interactions between energy, biodiversity, and human livelihoods is essential. Future research should explore the use of advanced modeling techniques, such as system dynamics or agent-based modeling, to simulate and predict the dynamic outcomes of various energy development scenarios.

(4) Effectiveness of Conservation Offset Programs

Investigating the effectiveness of conservation offset programs in mitigating the environmental impacts of energy projects is crucial. Future research should assess the ecological outcomes of offset initiatives, considering factors like habitat restoration, species protection, and the overall success of these programs in achieving their conservation objectives.

(5) Social and Cultural Dimensions

Delving into the social and cultural dimensions of energy development is imperative. Research should explore the cultural impact of energy projects on indigenous communities, traditional knowledge systems, and community resilience. Understanding how cultural factors intersect with environmental and economic considerations contribute to more culturally sensitive and sustainable energy practices.

(6) Economic Diversification Strategies

Examining strategies for economic diversification in community's dependent on energy extraction is essential. Research should investigate alternative livelihoods, skill development programs, and economic diversification initiatives to mitigate the socio-economic vulnerabilities associated with a heavy reliance on energy industries.

(7) Governance and Policy Analysis

Future research should focus on governance structures and policy frameworks governing energy development. Analyzing the effectiveness of current policies, identifying gaps, and proposing innovative governance models can guide policymakers in crafting regulations that balance energy needs with biodiversity conservation and community well-being [8, 36, 37].

(8) Technological Innovations for Sustainable Energy

Exploring and evaluating emerging technological innovations in the energy sector is vital. Future research should assess the feasibility and environmental impact of new technologies, such as advanced renewable energy systems, smart grids, and energy storage solutions, to promote more sustainable energy development practices.

(9) Community Engagement Strategies

Research should delve into effective community engagement strategies in decision-making processes related to energy projects. Understanding how communities can be actively involved, informed, and empowered in the decision-making process contributes to more inclusive and socially sustainable energy development.

(10) Climate Change Resilience

Investigating the resilience of ecosystems and communities to climate change induced by energy development is critical. Future research should assess the adaptive capacity of biodiversity and communities in the face of climate change, providing insights into strategies for enhancing resilience and mitigating negative impacts [7, 38–40].

(11) Cross-Sectoral Collaboration

Research should explore models of cross-sectoral collaboration between governmental bodies, private enterprises, non-profit organizations, and local communities. Understanding effective collaboration mechanisms can inform the development of multi-stakeholder partnerships that balance diverse interests and promote sustainable outcomes.

(12) Ethical Considerations in Energy Development

Research on the ethical dimensions of energy development is necessary. This includes investigating the ethical implications of resource extraction, potential conflicts of interest, and the ethical responsibilities of various stakeholders involved in energy projects.

(13) Education and Awareness Programs

Exploring the impact of education and awareness programs on communities living in proximity to energy development sites is essential. Future research should assess the effectiveness of initiatives aimed at enhancing environmental literacy, promoting sustainable practices, and fostering a sense of environmental stewardship among local populations [41].

(14) Gender Perspectives in Energy Projects

Analyzing the gender dimensions of energy projects and their impacts on local communities is crucial. Research should investigate how energy development projects affect gender roles, access to resources, and socio-economic opportunities, and explore strategies for promoting gender equity in the context of energy development.

(15) Global Comparative Studies

Conducting global comparative studies can provide a broader perspective on the challenges and opportunities associated with energy development, biodiversity conservation, and human livelihoods. Comparative analyses across regions with varying socio-economic conditions, regulatory frameworks, and ecological contexts can offer valuable insights into universal principles for sustainable development.

In conclusion, these recommendations outline diverse avenues for future research, each offering a unique opportunity to deepen our understanding of the intricate relationships between energy development, biodiversity conservation, and human livelihoods. By addressing these research gaps, scholars and practitioners can contribute to the development of evidence-based strategies and policies that promote sustainability, resilience, and harmony in the face of evolving environmental and societal challenges [42].

5.3.1 Prioritized Future Research Directions

Future research should focus on addressing several key empirical gaps identified in this study:

(1) Development of standardized trade-off metrics

There is a need for validated and comparable indicators, such as the proposed Energy–Biodiversity–Livelihood Trade-off Index (EBL-TI), to quantitatively assess socio-ecological trade-offs across different regions and energy systems [5].

(2) Comparative analysis of energy types

More empirical studies are required to systematically compare fossil fuel, large-scale renewable, and decentralized energy systems in terms of their biodiversity and livelihood impacts under different governance conditions.

(3) Longitudinal and cumulative impact assessment

Existing studies often focus on short-term impacts. Future work should examine long-term and cumulative ecological and socio-economic effects of energy development.

(4) Regional and context-specific studies

Greater attention is needed for region-specific dynamics, particularly in biodiversity hotspots and developing regions where governance structures, resource dependence, and vulnerability differ significantly.

(5) Integration of local and indigenous knowledge systems

Further research should explore how community knowledge can be systematically incorporated into energy planning and biodiversity conservation strategies.

6 Conclusion

This study provides empirical evidence of the complex and interdependent relationships among energy development, biodiversity conservation, and human livelihoods. The findings demonstrate that stakeholders perceive environmental degradation (mean = 4.28) and livelihood disruption (mean = 4.05) as major consequences of energy expansion, with statistically significant differences across stakeholder groups ($p < 0.05$). Correlation analysis further confirms a strong association between environmental degradation and livelihood insecurity (r = 0.57,

$p < 0.01$), highlighting the interconnected nature of ecological and socio-economic impacts. Importantly, the results reveal that trade-offs are highly context-dependent and vary significantly across energy types and geographical settings. Fossil fuel-based projects are consistently associated with higher levels of biodiversity loss, pollution, and long-term ecosystem degradation, whereas renewable energy projects, while generally less damaging, still impose localized pressures such as land-use change, habitat fragmentation, and community displacement. In biodiversity-sensitive regions and resource-dependent rural areas, these impacts are particularly pronounced, as local livelihoods are closely tied to ecosystem services. Conversely, in regions with stronger governance systems and effective environmental regulation, trade-offs are more effectively mitigated, indicating that institutional capacity plays a critical role in shaping outcomes. The findings also highlight that economic benefits of energy development (mean = 3.62) are unevenly distributed, often favoring corporate or national-level gains over local community well-being. This imbalance contributes to social tensions and reinforces the importance of participatory governance. Qualitative insights further demonstrate that lack of stakeholder engagement and inadequate compensation mechanisms exacerbate perceived injustices, particularly among vulnerable and indigenous populations. Based on these results, the study underscores that trade-offs between energy development, biodiversity conservation, and livelihoods are not inherently fixed but can be actively managed through integrated and adaptive governance approaches. Mechanisms such as biodiversity-sensitive spatial planning, stronger environmental impact assessments, equitable benefit-sharing models, and community participation are essential for reducing conflicts and improving sustainability outcomes.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on request.

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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