REVISTA TÓPICOS
ISSN 2965-6672 | Qualis A2

NATURE-BASED SOLUTIONS IN THE ENERGY TRANSITION: TOOLS, METRICS, AND CONTRIBUTIONS TO BIODIVERSITY AND SUSTAINABLE DEVELOPMENT

SOLUÇÕES BASEADAS NA NATUREZA NA TRANSIÇÃO ENERGÉTICA: FERRAMENTAS, MÉTRICAS E CONTRIBUIÇÕES PARA A BIODIVERSIDADE E O DESENVOLVIMENTO SUSTENTÁVEL

Ciências Biológicas, Engenharias, Ciências Sociais Aplicadas •

19/08/2026

REGISTRO DOI: 10.70773/revistatopicos/787110461

Ana Karen Silveira Pereira Caracas[1]

Esaú Aguiar Carvalho[2]

Francisco Denis de Oliveira Nascimento[3]

Francisco Jeandson Rodrigues da Silva[4]

Francisco José Lopes Cajado[5]

Gabrielly Oliveira da Silva[6]

Givanildo Ximenes Santana[7]

Helano Marcio Vieira Rangel[8]

Irene Mendes Fontes[9]

Raimundo Barroso Lutif Filho[10]

Rickardo Léo Ramos Gomes[11]

Roberto Augusto Caracas Neto[12]

Tadeu Dote Sá[13]

Tovyska Braga Dantas[14]

ABSTRACT

The expansion of renewable energy sources has been reshaping territories and energy policies, requiring approaches that reconcile decarbonization, nature conservation, and socio-environmental justice. In this context, Nature-based Solutions provide a framework for integrating climate change mitigation and adaptation with biodiversity protection and the promotion of sustainable development. The general objective of this article is to analyze the contributions of Nature-based Solutions to the energy transition, considering the tools and metrics used for their assessment and their impacts on biodiversity conservation and the promotion of sustainable development. The research adopted a qualitative approach, combining a bibliographic review and documentary research to analyze the role of Nature-based Solutions in the energy transition. In summary, the final considerations indicate that the analysis confirmed the relevance of Nature-based Solutions as a connecting element among energy transition, biodiversity conservation, and sustainable development; demonstrated that the proposed objectives were achieved; and highlighted the need for future studies to deepen the understanding of metrics, governance, and financing instruments that can enable the consistent and socially just implementation of these solutions in different contexts.
Keywords: Nature-based Solutions; energy transition; biodiversity; sustainable development.

RESUMO

A expansão das energias renováveis tem reconfigurado territórios e políticas energéticas, exigindo abordagens que conciliem descarbonização, conservação da natureza e justiça socioambiental. Nesse contexto, as Soluções Baseadas na Natureza constituem um referencial que permite integrar mitigação e adaptação às

mudanças climáticas com a proteção da biodiversidade e a promoção do desenvolvimento sustentável. O objetivo geral deste artigo é analisar as contribuições das Soluções Baseadas na Natureza para a transição energética, considerando as ferramentas e métricas utilizadas para sua avaliação e seus impactos na conservação da biodiversidade e na promoção do desenvolvimento sustentável. A pesquisa adotou abordagem qualitativa, articulando revisão bibliográfica e pesquisa documental para analisar o papel das Soluções Baseadas na Natureza na transição energética. Em síntese, as considerações finais indicam que a análise desenvolvida confirmou a relevância das SbN como eixo articulador entre transição energética, conservação da biodiversidade e desenvolvimento sustentável, demonstrou que os objetivos propostos foram alcançados e apontou a necessidade de aprofundar, em estudos futuros, a compreensão sobre métricas, governança e instrumentos de financiamento que viabilizem, em diferentes contextos, a implementação consistente e socialmente justa dessas soluções.
Palavras-chave: Soluções Baseadas na Natureza; transição energética; biodiversidade; desenvolvimento sustentável.

1. INTRODUCTION

The growing adoption of renewable energy sources, particularly through the development of wind farms and solar power plants, has been highlighted as a crucial solution for addressing climate change and as an essential response to the urgent need to decarbonize the different energy generation systems currently in operation. This transition is considered essential for reducing greenhouse gas emissions and ensuring a sustainable energy future. However, this paradigm shift does not take place without significant impacts on ecosystems, territories, and the communities that inhabit them. This makes it clear that the agendas of climate action, environmental conservation, and socio-environmental justice must be brought together in a balanced and integrated manner. In this regard, Nature-Based Solutions (NbS) provide a valuable framework for connecting ecosystem conservation, restoration, and sustainable management with the transformation of energy systems. In this way, these solutions can help bring together the agendas of climate, biodiversity, and sustainable development.

By connecting tools and metrics with the multiple contributions of Nature-Based Solutions to the energy transition, this research seeks to discuss and examine how these solutions can improve the planning, implementation, and evaluation of energy policies and projects. Accordingly, the present study aims to investigate in detail how the convergence of these approaches can strengthen the processes involved in the transition toward a sustainable energy system. In this context, the assessment of Nature-Based Solutions allows for a detailed analysis that goes beyond simply identifying opportunities for climate change mitigation and adaptation. It also considers the effects that these solutions may have on biodiversity, ecosystem services, and territorial development. It is therefore necessary for this analysis to take into account the interconnected complexity of all the dimensions involved, including the environmental, social, and economic aspects that are essential to this process.

The general objective of this study is to analyze the contributions of Nature-Based Solutions to the energy transition, considering the tools and metrics used for their assessment and their impacts on biodiversity conservation and the promotion of sustainable development. The specific objectives are to: understand the conceptual foundations and role of NbS in the energy transition, highlighting their contribution to addressing climate change and decarbonizing energy systems; identify and analyze the main tools, metrics, and indicators used to assess the effectiveness of NbS in the context of the energy transition; and discuss the contributions of NbS to biodiversity conservation and sustainable development, considering their environmental, social, and economic benefits.

Regarding the methodology, this research adopts a qualitative approach, combining a bibliographic review and documentary research to analyze the role of Nature-Based Solutions in the energy transition. The bibliographic review, based on scientific articles and books, made it possible to map the state of the art and critically organize the relevant concepts, metrics, and tools. The documentary research focused on the analysis of international frameworks related to ecological restoration, NbS assessment, biodiversity, NbS standards, and financing for nature, thereby strengthening the theoretical and methodological foundations of the study.

The article is organized into four main sections. The first presents the introduction, providing the context of the research topic, defining the objectives, and briefly describing the methodological approach. The second section details the methodology adopted. The third presents the theoretical framework, structured around three topics that address the foundations of NbS in the energy transition, assessment tools and metrics, and their contributions to biodiversity and sustainable development. Finally, the fourth section presents the concluding remarks, summarizing the main findings and pointing to possible directions for future research.

2. THEORETICAL FRAMEWORK

The theoretical framework was organized into three interconnected topics. The first discusses the conceptual foundations of Nature-Based Solutions, their relationship with the energy transition, and the main challenges and opportunities associated with incorporating them into decarbonization policies and projects.

The second examines the tools, metrics, and indicators used to assess the effectiveness of NbS, with emphasis on ecosystem services, carbon metrics, biodiversity indicators, natural capital approaches, and multicriteria assessment.

The third explores the contributions of NbS to biodiversity conservation and sustainable development, considering their environmental, social, and economic benefits, as well as their connection with the 2030 Agenda, the low-carbon economy, and sustainable territorial development.

2.1. Nature-Based Solutions And The Energy Transition: Foundations, Challenges, And Opportunities

Nature-Based Solutions (NbS) have become established over the past decades as an analytical framework capable of connecting ecosystem conservation, restoration, and sustainable management with social, climate, and economic objectives.

In their contemporary sense, the concept brings together different traditions and instruments, including the ecosystem approach, ecological restoration, ecological engineering, agroecology, ecosystem-based adaptation, REDD+, forest and landscape restoration, ecosystem-based disaster risk reduction, green infrastructure, and, more recently, natural climate solutions (Anderson, Suneja, and Dunjic, 2023; Seddon et al., 2020; Seddon et al., 2021; Eggermont et al., 2015; Nesshöver et al., 2017). This convergence does not eliminate conceptual tensions, but it does show that NbS now operate as a common language for environmental and energy policies guided by the integration of ecological integrity and collective well-being.

Seddon et al. (2020, p. 1524) explain that:

> *Nature-Based Solutions (NbS) have gained prominence as an umbrella term encompassing different concepts that involve working with nature for the benefit of society, such as the ecosystem approach, ecological restoration, ecological engineering, agroecology, EbA, REDD+, forest and landscape restoration (FLR), ecosystem-based disaster risk reduction (eco-DRR), green infrastructure (GI), and, more recently, natural climate solutions.*

From a normative perspective, the IUCN framework provides a particularly relevant basis for distinguishing NbS from actions that are merely ornamental or compensatory. By defining them as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2020, p. 2), the organization shifts the debate toward criteria related to ecological functionality, adaptability, and the co-production of benefits.

From a scientific perspective, this means recognizing that the quality of an NbS does not lie simply in its green appearance, but in its ability to sustain ecosystem processes, reduce risks, and produce verifiable effects on climate, water, soil, and biodiversity (Cohen-Shacham et al., 2016; Seddon et al., 2020).

In the energy transition, this context becomes particularly relevant because decarbonization is not limited to the technological replacement of fossil fuel sources. It also involves the spatial reconfiguration of energy production, transmission, and consumption systems.

The growing deployment of solar and wind power plants, together with the construction of transmission lines, energy storage systems, and logistics corridors, creates new pressures on habitats, fragmenting landscapes and affecting ecosystem services. This calls for solutions that not only minimize impacts but also seek to restore environmental functions whenever feasible.

In this regard, ecological restoration, watershed protection, and green infrastructure can contribute to an energy transition that is more closely aligned with long-term climate goals, provided that they are incorporated into planning from the outset rather than implemented only as corrective measures afterward (Rigolon et al., 2021; Seddon et al., 2021; Mccrary et al., 2021).

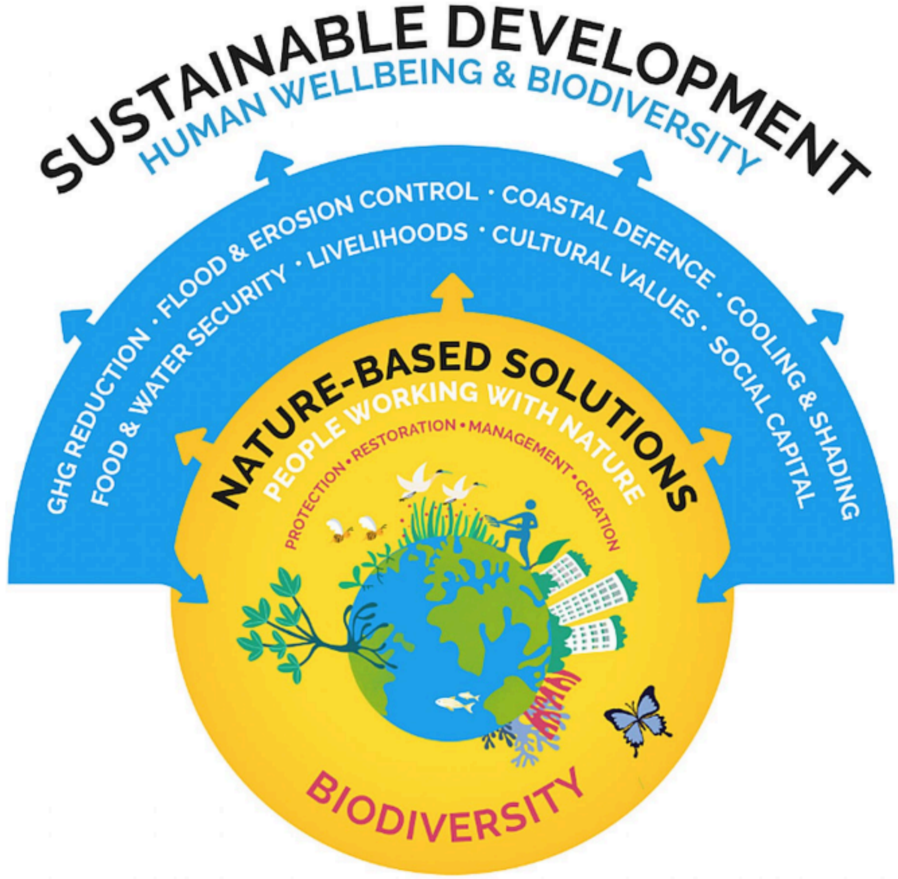
According to recent evidence, NbS are relevant to both climate change mitigation and adaptation, but this dual role depends on the institutional and ecological design of interventions. Projects aimed at forest restoration, mangrove conservation, soil management, and wetland protection can contribute to carbon sequestration, water regulation, and the reduction of socio-environmental vulnerabilities, while also strengthening the resilience of communities facing extreme events (Nesshöver et al., 2017).

However, the literature warns against oversimplification. It is not enough to label every intervention that uses vegetation as an NbS. It is essential to assess ecological additionality, the permanence of benefits, fairness in their distribution, and compatibility with local contexts (Cohen-Shacham et al., 2016; Eggermont et al., 2015; Nesshöver et al., 2017).

The interconnection presented in Figure 1 between green infrastructure and energy systems, particularly in relation to their operation, offers real opportunities for the ecological requalification of energy territories, especially when the goal is to harmonize renewable energy generation with biodiversity conservation. Vegetated strips, ecological corridors, riparian restoration, and the management of buffer areas can help mitigate erosion, maintain more stable microclimates, promote ecological connectivity, and improve social perceptions of energy projects.

The image presented synthesizes this logic by bringing together, in a single representation, sustainable development, human well-being, and biodiversity, along with benefits such as the reduction of greenhouse gas emissions, flood control, coastal protection, water security, the creation of livelihoods, and local cooling. This highlights the multifunctional nature of NbS in the current debate on energy and territory.

Figure 1. Integration of NbS with simultaneous climate, ecological, and social benefits



Source: Seddon et al. (2020)

However, the implementation of NbS in the energy sector should not be seen as a magic solution or as an alternative to policies aimed at directly reducing emissions. There are biophysical limits, conflicts over land use, territorial inequalities, and the risk of greenwashing when an energy project is presented as environmentally neutral even though this is not actually the case (Monaco, 2025). Therefore, the literature has emphasized that NbS should be assessed using robust metrics capable of capturing impacts on carbon, water, biodiversity, governance, and socio-environmental justice, while also taking into account different spatial and temporal scales. This becomes even more important in sectors that have a significant impact on territories, where renewable energy generation needs to be continuously monitored in relation to conservation, and where clear performance criteria are essential to ensure such compatibility (Seddon et al., 2020; Seddon et al., 2021; Mccrary et al., 2021).

In the field of international policy, NbS have become increasingly integrated into multilateral agendas on biodiversity, climate, and sustainable development, particularly when associated with ecosystem restoration, climate change adaptation, and the transition toward low-carbon economies. Their relevance lies precisely in their ability to bring together goals that, for a long time, were addressed separately: energy security, environmental protection, risk reduction, and the promotion of development. Thus, in the context of the energy transition, NbS should not be regarded as a peripheral complement, but rather as a key element of territorial planning and environmental governance, always supported by scientific evidence, sound assessment criteria, and a genuine commitment to biodiversity and sustainable development (IUCN, 2020; Cohen-Shacham et al., 2016; Eggermont et al., 2015; Nesshöver et al., 2017; Seddon et al., 2020; Seddon et al., 2021; Mccrary et al., 2021).

2.2. Tools, Metrics, And Indicators For Assessing Nature-Based Solutions

The consolidation of Nature-Based Solutions in the energy transition requires the use of assessment tools capable of capturing environmental, climate, social, and economic outcomes in an integrated manner. In this context, the IUCN definition (2020) provides a framework for linking the design of metrics to the very concept of NbS, as it emphasizes the need for simultaneous benefits to human well-being and biodiversity. This means that performance indicators cannot be limited to isolated biophysical parameters. They should also encompass governance processes, social participation, benefit distribution, and the adaptive robustness of projects within the context of the energy transition.

Recent debates on NbS assessment have highlighted the importance of structured and replicable protocols capable of guiding both the selection of indicators and their application across different territorial and sectoral scales. Dumitru and Wendling (2021, p. 25) emphasize that:

> *There is a clear need for robust methods, frameworks, and indicators that allow the quantification and analysis of the multiple levels of interaction associated with Nature-Based Solutions (NbS), from co-creation to implementation. Our handbook presents a protocol for selecting key NbS impact indicators and methods for their assessment, which can be applied to monitor baseline parameters.*

By emphasizing the entire trajectory of interventions, from participatory design to the operational phase, this handbook brings NbS assessment closer to the monitoring, transparency, and accountability agendas that are increasingly characteristic of contemporary climate and energy policies.

The literature on sustainability indicators applied to NbS has moved toward analytical frameworks that distinguish between, while also connecting, environmental, social, and economic dimensions. Raymond et al. (2017a) discuss general procedures for identifying indicators that reflect the specific objectives of interventions, emphasizing the need to align assessment goals with the social and ecological challenges being addressed. In subsequent studies, the same authors further develop the discussion of indicator-based monitoring, highlighting the importance of iterative processes in which results feed into cycles of learning and project adjustment (Raymond et al., 2017b). This perspective is particularly relevant to the energy transition, where the installation of new infrastructure requires continuous adjustments to the ecological and social conditions of territories.

The assessment of ecosystem services occupies a central position within this set of tools, since NbS operate largely through the maintenance or restoration of these services. Maes et al. (2020) emphasize that quantifying services such as climate regulation, flood protection, water recharge, habitat provision, and recreational benefits requires specific indicators that are sensitive to spatial and temporal variations. The authors also point out that integrating biophysical and socioeconomic indicators makes it possible to directly relate NbS performance to public policy goals, including those associated with the decarbonization of energy systems and energy security, thereby providing greater consistency for investment decisions.

Based on the contributions of IUCN (2020), Dumitru and Wendling (2021), Raymond et al. (2017a; 2017b), Maes et al. (2020), and Chausson et al. (2020), Table 1 summarizes a set of dimensions, tools, and metrics that can guide the assessment of Nature-Based Solutions in the context of the energy transition.

Table 1. Tools and metrics for assessing Nature-Based Solutions in the energy transition

Assessment dimension	Main tools, metrics, and indicators	Indicative references

Ecosystem services	Indicators of climate regulation, flood protection, carbon sequestration, water supply, habitat provision, recreation, and ecosystem health, combining ecosystem capacity and service flows	Maes et al. (2020); IUCN (2020)
Natural capital	Ecosystem service mapping and valuation models (e.g., **InVEST**), natural capital accounting, and land and energy use scenarios	Maes et al. (2020)
Carbon metrics	Indicators of carbon sequestration and storage, avoided emissions, and carbon balance generated by NbS, associated with the energy sector	IUCN (2020); Maes et al. (2020)
Biodiversity indicators	Species richness and composition, ecological integrity of habitats, landscape connectivity, and indicators of ecosystem status and trends	IUCN (2020); Maes et al. (2020)
Multicriteria assessment	Decision matrices, weighted criteria for environmental, social, economic, and governance dimensions, and the integration of indicators into participatory processes	Raymond et al. (2017a); Raymond et al. (2017b)
Co-creation and governance processes	Indicators of participation, co-production of knowledge, inclusion of actors, transparency, and alignment with ESG commitments	Dumitru; Wendling (2021); Raymond et al. (2017b)
Adaptive monitoring and management	Process, outcome, and impact indicator systems; periodic review cycles; and evidence-based project adjustments	Dumitru; Wendling (2021); Chausson et al. (2020)

Alignment between objectives and biodiversity	Indicators that capture synergies and trade-offs between mitigation, adaptation, conservation, and sustainable development across different scales	Chausson et al. (2020); IUCN (2020)

Source: IUCN (2020); Dumitru and Wendling (2021); Raymond et al. (2017a; 2017b); Maes et al. (2020); Chausson et al. (2020).

In the field of natural capital metrics, initiatives such as the Natural Capital Project, through the InVEST platform, have developed models and tools that translate changes in ecosystems into indicators of ecosystem services relevant to land-use and infrastructure planning. These models can be used, for example, to estimate carbon flows, water balances, soil erosion, flood risks, and the consequences of different intervention scenarios for human communities. When applied to energy transition projects, such tools can help identify scenarios in which NbS increase the resilience of energy infrastructure, reduce land-use conflicts, and strengthen the alignment between climate mitigation goals and biodiversity conservation (Maes et al., 2020).

The use of robust metrics and indicators is closely connected to the development of an evidence base capable of guiding policies and practices. Chausson et al. (2020, p. 6136) state that:

> *A rigorous scientific evidence base is essential for policies and practices related to Nature-Based Solutions (NbS), including target setting, planning, and governance, as well as for ensuring coherence among policy objectives. This involves identifying potential synergies and trade-offs among adaptation, mitigation, biodiversity conservation, and sustainable development objectives, as well as how these aspects vary across different scales.*

In the context of the energy transition, this means that we need evidence to compare NbS with conventional alternatives, understand costs and benefits over time, and identify situations in which poorly planned interventions may harm ecosystems and communities.

In addition to ecosystem service and natural capital indicators, recent studies have highlighted the importance of multicriteria assessments, adaptive monitoring systems, and ESG tools for improving the quality of NbS projects. In energy projects with complex territorial impacts, bringing together technical, environmental, social, and economic variables in decisions involving multiple stakeholders is particularly important (Raymond et al., 2017a; Raymond et al., 2017b), and multicriteria assessments are designed precisely to support this kind of integration. At the same time, incorporating ESG metrics into environmental initiatives can promote transparency, comparability, and alignment with international reporting standards, provided that these metrics are appropriately adapted to the specific characteristics of NbS and do not reduce their assessment to financial or corporate reputation indicators (Dumitru; Wendling, 2021).

Finally, the IUCN (2020), together with other international assessment protocols and normative guidelines, emphasizes that assessing the effectiveness of NbS requires methodological rigor combined with careful attention to local specificities. This means recognizing that indicators are not neutral, but rather the result of political and epistemological decisions about what is considered important to measure and value. The selection of tools, metrics, and indicators in the context of the energy transition should therefore be aligned with climate justice, territorial rights, and biodiversity conservation agendas, so that NbS are not used merely as a compensatory strategy. For NbS to make a meaningful contribution to the decarbonization of energy systems and to sustainable development, it is essential to build monitoring and adaptive management systems grounded in scientific evidence and participatory processes (IUCN, 2020; Dumitru; Wendling, 2021; Chausson et al., 2020; Maes et al., 2020).

2.3. Contributions Of Nature-Based Solutions To Biodiversity And Sustainable Development

Nature-Based Solutions have been presented as an integrated response to the biodiversity crisis and socio-environmental inequalities, bringing together conservation, restoration, and the provision of ecosystem services across different territorial contexts (Anderson, Suneja, and Dunjic, 2023). The IPBES Global Assessment Report (2019) shows that human pressures have been causing an accelerated erosion of biological diversity and the services that support human well-being, requiring profound changes in current development models. Díaz et al. (2019) reinforce that this decline is directly associated with patterns of production and consumption that disrupt ecosystems and increase social vulnerabilities, making NbS particularly relevant to energy transition processes that seek to reconcile decarbonization, social justice, and ecological integrity.

In this context, biodiversity conservation and restoration emerge as key elements of NbS, particularly when linked to climate change mitigation and adaptation agendas. Gann et al. (2019, p. 3) point out that:

> *Ecological restoration, when implemented effectively and sustainably, contributes to protecting biodiversity; improving human health and well-being; increasing food and water security; providing goods, services, and economic prosperity; and supporting climate change mitigation, resilience, and adaptation.*

By explicitly connecting ecological restoration, water security, and economic prosperity, these international principles and standards provide guidance for the implementation of NbS in projects that combine the recovery of degraded ecosystems, the ecological requalification of energy landscapes, and the strengthening of local livelihoods.

The evidence compiled by Eggermont et al. (2015) indicates that NbS can generate simultaneous benefits for biodiversity and human well-being, particularly in urban and peri-urban contexts, where interventions such as green infrastructure, wetland restoration, and vegetation-based systems can help reduce risks, improve environmental quality, and strengthen social cohesion. At the same time, the IPBES Report (2019) and Díaz et al. (2019) warn that these benefits are not automatically or equally distributed, as they depend on institutional arrangements, regulatory frameworks, and governance patterns. In the context of the energy transition, this means that projects combining renewable energy generation and NbS need to address power asymmetries, land-use conflicts, and historical inequalities, otherwise they may end up reproducing socio-environmental injustices.

In the field of hydrometeorological risk reduction and water security, Ruangpan et al. (2020) show that NbS, such as floodplain restoration, riparian reforestation, wetland restoration, and ecosystem-based coastal solutions, can reduce exposure to floods, storms, and erosion while also strengthening climate regulation and water provision services.

According to Ruangpan et al. (2020, p. 258):

> *The literature on Nature-Based Solutions (NbS) and related concepts increasingly refers to the multiple benefits resulting from social, economic, and environmental improvements. This is because NbS are considered sustainable solutions that use ecosystem services to provide multiple benefits for human well-being and the environment, thereby distinguishing them from grey infrastructure. In addition, these multiple benefits of NbS can contribute to achieving many of the targets of the 2030 Agenda for Sustainable Development.*

This perspective is particularly relevant to energy projects located within watersheds, where combining physical infrastructure with NbS can strengthen climate resilience and water security.

The economic dimensions of NbS have gained increasing attention, particularly in discussions surrounding climate finance, green investment, and the low-carbon economy. The *State of Finance for Nature* report, published by UNEP (2023), points out that although investment in NbS is growing, there is still a significant gap between financial flows directed toward nature and those that continue to support activities that degrade ecosystems. This highlights the need to realign subsidies and incentives. In this context, NbS associated with the energy transition can play a strategic role by directing resources toward projects that simultaneously reduce emissions, restore ecosystems, and expand economic opportunities in vulnerable territories, thereby strengthening the coherence among environmental, energy, and development policies.

The connection between NbS and the Sustainable Development Goals becomes particularly clear when considering targets related to water, climate, cities, energy, biodiversity, and inequality reduction (Anderson, Suneja, and Dunjic, 2023). IPBES (2019) and Díaz et al. (2019) argue that conservation and restoration actions, when designed with a transformative approach, can help redirect development pathways, bringing sectoral policies closer together and promoting synergies among climate, biodiversity, and social inclusion goals. Eggermont et al. (2015) further emphasize that NbS provide a common language for connecting science, management, and public policy, which makes them particularly suitable for sustainable territorial development and low-carbon economy programs, including those focused on reshaping energy systems.

To systematize these relationships, Table 2 summarizes the main contributions of NbS to biodiversity and sustainable development across different environmental, social, and economic dimensions, with a focus on energy transition contexts.

Table 2. Contributions of Nature-Based Solutions to biodiversity and sustainable development in the energy transition

Dimension	Contributions of NbS	Indicative references
Biodiversity and ecosystems	Conservation and restoration of habitats, increased ecological connectivity, and recovery of degraded ecosystems	IPBES (2019); Díaz et al. (2019); Gann et al. (2019); Eggermont et al. (2015)
Ecosystem services and water	Improved water regulation, reduced flooding and erosion, and protection of watersheds and wetlands associated with energy infrastructure	Ruangpan et al. (2020); IPBES (2019)

Climate resilience	Reduced hydrometeorological risks, increased adaptive capacity of communities and infrastructure, and mitigation of climate impacts	Ruangpan et al. (2020); Gann et al. (2019)
Social benefits	Improved well-being, health, and safety, creation of green jobs, strengthened social cohesion, and inclusion of vulnerable groups	IPBES (2019); Díaz et al. (2019); Eggermont et al. (2015)
Economic benefits	Opportunities in the low-carbon economy, generation of local income, and reduced infrastructure and disaster-related costs	UNEP (2023); Gann et al. (2019); Ruangpan et al. (2020)
2030 Agenda and SDGs	Integrated contributions to targets related to water, climate, energy, cities, biodiversity, and inequality reduction	IPBES (2019); Díaz et al. (2019); Ruangpan et al. (2020); Anderson, Suneja, and Dunjic (2023)
Territorial development	Sustainable territorial planning, coordination among environmental and energy policies, and regional development	Eggermont et al. (2015); IPBES (2019); UNEP (2023)

Source: IPBES (2019); Díaz et al. (2019); Eggermont et al. (2015); Ruangpan et al. (2020); Anderson, Suneja, and Dunjic (2023); UNEP (2023); Gann et al. (2019).

The evidence summarized in Table 2 shows that NbS can serve as an integrating element linking biodiversity conservation, climate resilience, and sustainable territorial development, particularly when they are connected to the energy transition and the 2030 Agenda.

Finally, the contributions discussed suggest that NbS should not be treated as peripheral or merely compensatory tools in energy transition projects. IPBES (2019) and Díaz et al. (2019) point out that addressing the decline of life on Earth requires profound changes in economic, technological, and institutional systems, including the redirection of investments and policies toward solutions that recognize nature as living infrastructure. In this regard, Eggermont et al. (2015), Ruangpan et al. (2020), Gann et al. (2019), Anderson, Suneja, and Dunjic (2023), and UNEP (2023) converge in highlighting that NbS, when grounded in principles of ecological restoration and social justice and aligned with global climate and biodiversity goals, can make a meaningful contribution to a low-carbon economy and to more equitable and sustainable development pathways.

3. METHODOLOGY

It is essential to have a methodological strategy that brings together conceptual, normative, and empirical debates from different areas of knowledge in order to investigate Nature-Based Solutions in the energy transition, particularly with regard to the tools, metrics, and contributions associated with biodiversity and sustainable development.

The methodology adopted was guided by the complexity of the subject, as it simultaneously involves energy policies, environmental conservation, financial mechanisms, and territorial experiences in the implementation of NbS, requiring particular attention to the relationships between science, management, and governance (Lakatos; Marconi, 2020).

A qualitative approach was adopted because it is more concerned with understanding meanings, processes, and contexts than with conducting numerical measurements. Within the broader landscape of global scientific research, qualitative methods are essential for interpreting complex social and environmental phenomena, allowing analyses that take into account different perspectives, timeframes, and scales (Denzin; Lincoln, 2018).

This qualitative research, which prioritizes the analysis of discourses, documents, and theoretical frameworks, focuses on conceptual development and the construction of critical interpretations of the energy transition guided by NbS. It is consistent with the view that qualitative methods are particularly suitable for investigating practices, policies, and sociocultural contexts (Lakatos; Marconi, 2020; Denzin; Lincoln, 2018).

The investigation employed two research methods: a bibliographic review and documentary research. The literature on research methods emphasizes that a bibliographic review is a fundamental stage of any investigation because it helps establish the state of the art, identify gaps in knowledge, situate the study in relation to existing research, and provide a theoretical basis for the analysis (Lakatos; Marconi, 2020; Braucks et al., 2025).

Documentary research, in turn, is crucial for enabling a detailed analysis of institutional, normative, and technical documents, helping to understand the regulatory, policy, and epistemological foundations that guide a particular field of practice (Salge; Oliveira; Silva, 2021).

The bibliographic review was based on scientific articles and scholarly books published in academic journals and selected because of their relevance to the topic and their contribution to current debates on NbS, the energy transition, biodiversity, and sustainable development.

As Braucks et al. (2025) point out, bibliographic research can itself constitute a scientific methodology when it is conducted with rigor in the selection, systematization, and analysis of sources, allowing new syntheses and interpretations to be developed from previously published works. Therefore, the bibliographic review conducted in this study was not intended merely to gather references, but rather to critically organize the concepts, analytical categories, and empirical evidence that support the discussions presented here.

The documentary research focused on the analysis of key documents produced by organizations recognized for their work on NbS, ecological restoration, and global biodiversity and climate policies.

The documents examined included the *International Principles and Standards for the Practice of Ecological Restoration* (Gann et al., 2019), which provides guidelines for ecological restoration practices; the handbook *Evaluating the Impact of Nature-Based Solutions: A Handbook for Practitioners* (Dumitru; Wendling, 2021), which provides guidance for assessing the impacts of NbS across multiple dimensions; the *Global Assessment Report on Biodiversity and Ecosystem Services*, published by IPBES (2019); the *IUCN Global Standard for Nature-based Solutions* (IUCN, 2020); and the report *State of Finance for Nature: The Big Nature Turnaround*, published by UNEP (2023). In accordance with Salge, Oliveira, and Silva (2021), these documents were analyzed according to criteria of authenticity, credibility, representativeness, and significance, ensuring that the interpretations developed were grounded in consistent and widely recognized sources.

The combination of bibliographic review and documentary research proved to be an appropriate strategy because it made it possible, on the one hand, to ground the analysis in current theoretical and empirical debates and, on the other, to engage directly with standards, guidelines, and reports that shape NbS practices at the global level. As Lakatos and Marconi (2020) and Braucks et al. (2025) emphasize, combining different methodological procedures can enrich the understanding of the research object by integrating complementary perspectives and reducing the limitations inherent in each method when used in isolation.

In the context of this research, this integration made it possible to develop a more consistent analytical framework in which concepts, metrics, instruments, and experiences are interpreted in light of widely recognized scientific and institutional references. This approach provides greater rigor, coherence, and depth to the discussion of the role of NbS in the energy transition.

4. FINAL CONSIDERATIONS

Nature-Based Solutions in the energy transition represent a strategic field of research for building pathways that reconcile decarbonization, biodiversity conservation, and the promotion of sustainable development. By bringing together conceptual frameworks, assessment metrics, and practical experiences, the research developed here contributes to a deeper understanding of how energy systems can be reorganized in ways that respect ecological limits and socio-environmental justice, while responding in an integrated manner to climate, environmental, and development agendas.

Throughout the analytical process, the general objective of examining the contributions of NbS to the energy transition, considering assessment tools and metrics and their effects on biodiversity and sustainable development, was effectively achieved. Likewise, the first specific objective was addressed by exploring the conceptual foundations of NbS and their role in addressing climate change and decarbonizing energy systems; the second was addressed by identifying and discussing tools, indicators, and monitoring frameworks that make it possible to assess the effectiveness of these solutions; and the third was fulfilled by highlighting the environmental, social, and economic benefits of NbS for biodiversity conservation and the promotion of more sustainable development pathways.

In the first part of the theoretical framework, the analysis showed that NbS provide a framework capable of bringing together different approaches to ecosystem conservation, restoration, and management, while connecting climate change mitigation and adaptation with energy transition policies. It became clear that, although these solutions offer significant opportunities to align renewable energy generation with nature conservation, they also face challenges related to land-use conflicts, power asymmetries, the risk of greenwashing, and the need for regulatory and institutional frameworks that ensure both their ecological integrity and social legitimacy.

The second part of the theoretical framework highlighted the central role of tools, metrics, and indicators in improving the assessment of NbS in energy-related contexts, with particular emphasis on the integration of ecosystem service indicators, carbon metrics, biodiversity indicators, natural capital approaches, multicriteria assessments, ESG tools, and adaptive monitoring systems. The analysis showed that the robustness of these metrics is essential for building solid evidence bases capable of informing planning and investment decisions, while also ensuring transparency and accountability in projects that combine NbS with energy infrastructure.

The third part of the theoretical framework demonstrated that NbS can make a meaningful contribution to biodiversity conservation and restoration, the recovery of degraded ecosystems, water security, and climate resilience, while also generating social and economic benefits, particularly in vulnerable territories. The analysis further showed that these contributions are directly connected to the objectives of the 2030 Agenda and to the development of a low-carbon economy, reinforcing the importance of incorporating NbS into sustainable territorial development strategies and renewable energy expansion programs.

Considering the complexity of the topic, future research can move forward in at least three complementary directions. First, comparative empirical studies in different regional contexts could examine, using standardized indicators, the effects of NbS associated with wind farms, solar power plants, and other energy infrastructure on biodiversity, ecosystem services, and social well-being. Second, further research could investigate governance models, institutional arrangements, and legal instruments that support the effective incorporation of NbS into energy, climate, and development policies, with particular attention to socio-environmental conflicts and the participation of local communities. Third, future studies could explore the integration of NbS, technological innovation, and economic instruments, including financing mechanisms and ecosystem service valuation, in order to support the redirection of financial flows toward initiatives that simultaneously strengthen nature and advance the energy transition.

REFERENCES

ALBERT, C. et al. Addressing societal challenges through nature-based solutions: how can landscape planning and governance research contribute? *Landscape and Urban Planning*, v. 182, p. 12–21, 2019. https://doi.org/10.1016/J.LANDURBPLAN.2018.10.003.

ANDERSON, V.; SUNEJA, M.; DUNJIC, J. Sensing and measurement techniques for evaluation of nature-based solutions: A state-of-the-art review. *Land*, v. 12, n. 8, p. 1477, 2023. https://doi.org/10.3390/land12081477

BRAUCKS, J. B.; AZEVEDO, G. P.; NEUBAUER, V. S.; ECKERT, N. H. Pesquisa Bibliográfica como Metodologia de Pesquisa Científica . *RELACult - Revista Latino-Americana de Estudos em Cultura e Sociedade*, [S. l.], v. 11, 2025. https://doi.org/10.23899/g0q8kq90.

CHAUSSON, A. et al. Mapping the effectiveness of nature-based solutions for climate change adaptation. *Global Change Biology*, v. 26, n. 11, p. 6134–6155, 2020. https://doi.org/10.1111/gcb.15310.

COHEN-SHACHAM, E. et al. *Nature-based Solutions to Address Global Societal Challenges*. Gland: IUCN, 2016. https://doi.org/10.2305/IUCN.CH.2016.13.en.

DENZIN, N. K.; LINCOLN, Y. S. *The Sage handbook of qualitative research* (5th ed.). Sage, 2018.

DÍAZ, S. et al. Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, v. 366, n. 6471, 2019. https://doi.org/10.1126/science.aax3100.

DUMITRU, A.; WENDLING, L. *Evaluating the Impact of Nature-Based Solutions:* A Handbook for Practitioners. Luxembourg: Publications Office of the European Union, 2021. ISBN 978-92-76-22821-9. https://doi.org/10.2777/244577.

EGGERMONT, H. et al. Nature-based solutions: new influence for environmental management and research in Europe. ***Nature***, v. 519, p. 409–410, 2015. https://doi.org/10.14512/gaia.24.4.9.

GANN, G. D. et al. *International Principles and Standards for the Practice of Ecological Restoration*. 2. ed. Washington, D.C.: Society for Ecological Restoration, 2019. https://doi.org/10.1111/rec.13035.

IPBES. *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* IPBES secretariat, Bonn, Germany. 1144 pages. 2019. ISBN: 978-3-947851-20-1. Disponível em: https://www.ipbes.dk/wp-content/uploads/2021/10/IPBES-GLOBAL-FULL-REPORT.pdf. Acesso em: 07/2026.

IUCN. *IUCN Global Standard for Nature-based Solutions:* a User-Friendly Framework for the Verification, Design and Scaling Up of NbS. Gland: IUCN, 2020. ISBN: 978-2-8317-2060-9. https://doi.org/10.2305/IUCN.CH.2020.08.es.

LAKATOS, E. M.; MARCONI, M. de A. *Fundamentos de metodologia científica.* 17ª ed. São Paulo: Atlas, 2020.

MAES, J. et al. Mapping and assessment of ecosystems and their services: an EU-wide assessment of ecosystems. *Science of the Total Environment,* v. 741, 2020. ISBN: 978-92-76-17833-0 (online); https://doi.org/10.2760/757183.

MCCRARY, M. D. et al. Technology interactions and potential environmental impacts of offshore wind energy. *Renewable and Sustainable Energy Reviews*, v. 146, 2021.

MONACO, S. The other side of sustainability: Contradictions and risks in contemporary green innovations. *Sustainability*, v. 17, n. 10, p. 4687, 2025. https://doi.org/10.3390/su17104687.

NESSHÖVER, C. et al. The science, policy and practice of nature-based solutions: an interdisciplinary perspective. *Science of the Total Environment,* v. 579, p. 1215–1227, 2017. https://doi.org/10.1016/j.scitotenv.2016.11.106.

RAYMOND, C. M. et al. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy*, v. 77, p. 15–24, 2017a. https://doi.org/10.1016/j.envsci.2017.07.008.

RAYMOND, C. M. et al. An impact evaluation framework for nature-based solutions in urban areas. *Environmental Science & Policy*, v. 66, p. 14–24, 2017b. ISBN: 978-1-906698-62-1. Disponível em: https://ora.ox.ac.uk/objects/uuid:3ecfc907-1971-473a-87f3-63d1204120f0/files/m4ba25c7377aa2d15cd3aa638cf475561. Acesso em: 07/2026.

RIGOLON, A. et al. Green space and health equity: a systematic review on the potential of green space to reduce health disparities. *International journal of environmental research and public health*, v. 18, n. 5, p. 2563, 2021. https://doi.org/10.3390/su17104687.

RUANGPAN, L. et al. Nature-based solutions for hydro-meteorological risk reduction: a state-of-the-art review. *Natural Hazards and Earth System Sciences*, v. 20, p. 243–270, 2020. https://doi.org/10.5194/nhess-20-243-2020.

SALGE, E. H. C. N.; OLIVEIRA, G. S. de; SILVA, L. S. Saberes para a Construção da Pesquisa Documental. *Revista Prisma*, v. 2, n. 1, p. 123-139, 25 dez. 2021. Disponível em: https://revistaprisma.emnuvens.com.br/prisma/article/view/47. Acesso em: 08/2026.

SEDDON, N. et al. Getting the message right on nature-based solutions to climate change. *Global Change Biology*, v. 27, n. 8, p. 1518–1546, 2021. https://doi.org/10.1111/gcb.15513.

SEDDON, N. et al. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological*

Sciences, v. 375, n. 1794, 20190120, 2020. https://doi.org/10.1098/rstb.2019.0120.

UNEP. *State of Finance for Nature:* The Big Nature Turnaround. Nairobi: United Nations Environment Programme, 2023. Disponível em: https://wedocs.unep.org/handle/20.500.11822/44278. Acesso em: 08/2026.

---

[1] Undergraduate Student, Electrical and Computer Engineering, São Carlos School of Engineering (EESC/USP).

[2] Dr. in Biotechnology - Federal University of Amazonas

[3] Bachelor’s degree in Accounting from Centro Universitário Estácio FiC

[4] Dr. in Electrical Engineering - UFC.

[5] Prof. Dr. In Agricultural Biotechnology (RENORBIO – UFC).

[6] Master’s Degree in Biotechnology of Natural Resources – UFC

[7] Ph.D. in Genetics, Conservation, and Evolutionary Biology National Institute of Amazonian Research

[8] Master’s Degree in Constitutional Legal Order – Federal University of Ceará

[9] Postgraduate Degree in Criminal Law from UniAteneu University Center

[10] Master's Degree in Economics – UFC

[11] Dr. In Biological Sciences (Cultural Title) – FICL; Master's Degree in Crop Science – UFC

[12] Doctoral Student at the Academy of the National Institute of Industrial Property

[13] Prof. Dr. In Regional Development from the University of Barcelona

[14] MBA in Renewable Energy Management. FBUNI/IEL