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NATURE-POSITIVE ENERGY TRANSITION: INNOVATION AND REGENERATIVE DEVELOPMENT IN NORTHEASTERN BRAZIL

TRANSIÇÃO ENERGÉTICA POSITIVA PARA A NATUREZA: INOVAÇÃO E DESENVOLVIMENTO REGENERATIVO NO NORDESTE BRASILEIRO

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ABSTRACT

Contemporary energy transition extends beyond the replacement of fossil fuels with renewable sources, encompassing technological, economic, environmental, and territorial transformations. In the Brazilian Northeast, the expansion of renewable energy increases development opportunities but requires planning capable of integrating energy production with the conservation, restoration, and enhancement of ecosystems. In this context, the general objective of this study is to analyze how innovation associated with the energy transition can contribute to the construction of a regenerative development model in the Brazilian Northeast by integrating the expansion of renewable energy with the conservation, restoration, and enhancement of regional ecosystems. The research is characterized as qualitative, exploratory, and descriptive, conducted through a literature review and documentary research. The literature review included dissertations, scientific articles, book chapters, and books, while the documentary research examined reports, institutional documents, and publications by national and international organizations related to energy transition, sustainable development, and nature conservation. The results demonstrated that the energy transition can adopt a nature-positive orientation when integrated with innovation, territorial planning, and ecosystem restoration. It is concluded that the expansion of renewable energy requires integration among energy, environmental, economic, and social dimensions, contributing to a regenerative development approach and indicating possibilities for future research on its territorial and socioecological effects.

Keywords: Energy transition; Innovation; Regenerative development; Renewable energy.

RESUMO

A transição energética contemporânea ultrapassa a substituição de fontes fósseis por renováveis, envolvendo transformações tecnológicas, econômicas, ambientais e territoriais. No Nordeste brasileiro, a expansão das energias renováveis amplia oportunidades de desenvolvimento, mas requer planejamento capaz de articular a produção energética à conservação, recuperação e valorização dos ecossistemas. Nesse contexto, o estudo tem como objetivo geral analisar como a inovação associada à transição energética pode contribuir para a construção de um modelo de desenvolvimento regenerativo no Nordeste brasileiro, articulando a expansão das energias renováveis à conservação, recuperação e valorização dos ecossistemas regionais. A pesquisa caracteriza-se como qualitativa, exploratória e descritiva, desenvolvida mediante revisão bibliográfica e pesquisa documental. A revisão contemplou dissertações, artigos científicos, capítulos de livros e livros, enquanto a pesquisa documental examinou relatórios, documentos institucionais e publicações de organismos nacionais e internacionais relacionados à transição energética, ao desenvolvimento sustentável e à conservação da natureza. Os resultados evidenciaram que a transição energética pode assumir uma orientação positiva para a natureza quando articulada à inovação, ao planejamento territorial e à recuperação dos ecossistemas. Conclui-se que a expansão das energias renováveis requer integração entre dimensões energéticas, ambientais, econômicas e sociais, contribuindo para uma abordagem de desenvolvimento regenerativo e indicando possibilidades para futuras pesquisas sobre seus efeitos territoriais e socioecológicos.

Palavras-chave: Transição energética; Inovação; Desenvolvimento regenerativo; Energias renováveis.

1. INTRODUCTION

Energy transition is one of the most significant current transformations in the structure of production, consumption, and infrastructure systems, particularly in relation to the need to reduce dependence on fossil fuels and increase the contribution of renewable energy sources. However, changes in energy technologies and energy mixes cannot be viewed solely from the perspective of decarbonization, since the expansion of solar, wind, biomass, and other renewable energy projects also generates impacts on territories, natural resources, and socioeconomic dynamics. In this context, innovation becomes strategic by enabling new approaches to planning, production, management, and coordination among energy, the economy, society, and nature.

In Northeastern Brazil, the expansion of renewable energy takes place in a territory characterized by abundant natural resources and diverse environmental, social, and economic configurations. This context creates a broad range of development opportunities associated with the energy transition, while also requiring careful attention to project implementation conditions, biodiversity conservation, the restoration of degraded areas, and the participation of diverse territorial stakeholders. Therefore, the concept of a nature-positive energy transition shifts the focus from an approach centered on minimizing environmental damage toward a proposal that integrates energy generation, innovation, conservation, and ecosystem restoration, providing a foundation for a regenerative development model in Northeastern Brazil.

Against this background, the present research is guided by the following question: How can innovation associated with the energy

transition contribute to a regenerative development model that reconciles the expansion of renewable energy with the conservation and restoration of ecosystems in Northeastern Brazil? This question directs the analysis toward the relationships among innovation, energy transition, and environmental conservation, considering that the transformation of energy systems may be accompanied by strategies capable of generating environmental, territorial, and socioeconomic benefits.

To address the research question, the study establishes the following general objective: To analyze how innovation associated with the energy transition can contribute to the development of a regenerative development model in Northeastern Brazil, capable of integrating the expansion of renewable energy with the conservation, restoration, and enhancement of regional ecosystems. The following specific objectives were established: 1. To investigate the relationships among energy transition, innovation, and ecosystem conservation, considering the foundations of a nature-positive approach. 2. To analyze the challenges and opportunities associated with the expansion of renewable energy in Northeastern Brazil, considering its territorial, environmental, technological, and socioeconomic impacts. 3. To discuss innovation and regenerative development strategies capable of integrating the expansion of renewable energy with ecosystem conservation and restoration, thereby fostering sustainable regional development in Northeastern Brazil.

Regarding the methodological procedures, the research adopts a qualitative approach with an exploratory and descriptive character, seeking to interpret the relationships established among energy transition, innovation, regenerative development, and ecosystem

conservation. Two research procedures were combined: a literature review and documentary research. The literature review brought together dissertations, scientific articles, book chapters, and books related to the subject, while the documentary research examined reports, institutional documents, and publications produced by national and international organizations addressing energy transition, sustainable development, and nature conservation. The combination of these procedures made it possible to bring together different theoretical and documentary perspectives to support the proposed analysis.

The article is structured into four sections, in addition to this Introduction: Methodology, Theoretical Framework, and Final Considerations. The first section presents the contextualization of the research problem, the research question, and the objectives guiding the study. The second describes the methodological approach and the procedures employed in the investigation. The third develops the theoretical framework, organized around the relationships among energy transition, innovation, ecosystem conservation, and regenerative development. Finally, the fourth section presents the final considerations, revisiting the main aspects analyzed and the study's contributions to understanding an energy transition integrated with the conservation and restoration of ecosystems in Northeastern Brazil.

2. THEORETICAL FRAMEWORK

The theoretical framework was organized into three interconnected topics that progressively guide the discussion on energy transition and its relationships with innovation and socio-environmental sustainability. The first topic, “3.1 Energy Transition, Innovation, and

the Nature-Positive Perspective," addresses the foundations of the energy transition, emphasizing the role of innovation and the need to incorporate nature conservation into transformations of energy systems. The second, "3.2 Expansion of Renewable Energy in Northeastern Brazil: Opportunities, Challenges, and Territorial Implications," analyzes the possibilities and challenges associated with the expansion of renewable energy sources in the region, considering their environmental, territorial, technological, and socioeconomic effects. Finally, the third topic, "3.3 Innovation and Regenerative Development: Integrating Renewable Energy, Conservation, and Ecosystem Restoration," discusses strategies capable of bringing energy expansion closer to ecosystem conservation and restoration by integrating innovation, territorial planning, governance, and regenerative development.

2.1. Energy Transition, Innovation, And The Nature-Positive Perspective

Energy transition cannot be reduced to the replacement of fossil fuels with renewable sources. What is at stake is a reorganization of energy production, conversion, distribution, and consumption systems that encompasses technological, territorial, economic, and institutional dimensions and requires changes in innovation patterns and forms of sectoral organization. It therefore makes greater analytical sense to approach it as a multidimensional process in which technological innovation develops alongside public policy formulation, productive reorganization, and the creation of new institutional capacities (Silva; Barros, 2021). This perspective shifts the analysis from the energy mix itself toward the process through which it is reconfigured.

The same reasoning applies when energy, innovation, and economic development are considered together: transformations in the energy sector do not remain confined to it, but instead reconfigure productive structures as a whole. Paixão and Abaide (2026, p. 2) highlight this relationship by stating:

> *The relationship between energy and economic development constitutes one of the central axes of the structural transformations shaping contemporary societies. Historically, economic growth has been associated with increasing energy consumption, primarily derived from fossil fuels such as coal, oil, and natural gas. Although this model has promoted substantial industrial and technological advances, it has become increasingly unsustainable in light of accelerating climate change, environmental degradation, and instability in energy markets. Renewable energy sources therefore emerge as a strategic alternative, not only from an environmental perspective but also as a potential instrument for the reconfiguration of economic development models.*

In this context, innovation does not refer solely to the development of more efficient equipment or the incorporation of new energy sources. It encompasses technological, organizational, and institutional changes capable of altering the very patterns of energy production and use. This is indicated by the review conducted by Cardoso, Camilo, and Picolo (2024), which shows that innovations in the electricity sector involve the emergence of new technologies, management models, and approaches to reorganizing the energy system. Understood in this way, innovation functions as the point of

connection between technological transformation and energy systems aligned with long-term environmental and socioeconomic goals.

There is also an economic dimension that cannot be treated separately, insofar as the transition is linked to the generation of investment, employment, and new productive activities. The International Renewable Energy Agency states that “renewables are today a significant driver of investment and employment” (IRENA, 2022, p. 18), and this dynamic can foster the formation of productive chains associated with renewable technologies, scientific research, intellectual property, and industrialization. In Brazil, it is precisely this relationship between energy and innovation that Caracas; Gomes et al. (2026) examine by relating the energy transition to technological development and the interfaces among renewable energy sources, innovation, and intellectual property.

However, the expansion of renewable energy takes place in concrete spaces characterized by environmental, economic, and social features that vary from one location to another, which is why the territorial perspective becomes part of the discussion. Cataia and Duarte (2022) emphasize the need to problematize the energy transition from a territorial perspective rather than reducing it to the technological replacement of energy sources. In Northeastern Brazil, this approach makes it possible to consider simultaneously the availability of renewable resources, land-use patterns, existing economic activities, and ecosystem conservation. Innovation and energy transition, in this context, only make sense when analyzed in connection with the particularities of the territories where projects are actually implemented.

The articulation between renewable energy and regional development also depends on the capacity to transform natural resources into knowledge, technology, investment, and economic activities that generate greater added value. According to ECLAC (2020, p. 34), “renewable energies can contribute to more inclusive development in Latin America.” In Brazil, Corrêa (2021) demonstrates the importance of innovation and economic development policies associated with wind energy and solar photovoltaic initiatives. This discussion makes it possible to recognize that the energy transition does not have a single configuration: its form changes according to the public policies adopted, the institutional capacities available, and the mechanisms that connect innovation, production, and regional development in each context.

The nature-positive approach shifts this debate toward another analytical field: when evaluating an energy system, both its capacity to reduce emissions and its relationship with biodiversity and ecosystems must be considered. This means incorporating conservation, environmental restoration, and ecological integrity into project planning from the outset, rather than treating them as subsequent corrective measures. Along these lines, Gomes (2025) brings together different trends in renewable energy innovation, making it possible to understand the sector as a space of continuous technological transformation rather than as a state achieved once and for all. The change in perspective therefore lies in associating energy innovation with the development of solutions capable of reconciling economic performance, impact reduction, and improvements in environmental conditions.

There are also social and political dimensions accompanying the transformation of energy systems that cannot be excluded from

discussions on sustainability. Torres, Miguel, and Martins (2024) demonstrate that the narratives and imaginaries of different stakeholders shape how the energy transition is understood and legitimized in Brazil. This dimension is relevant because energy projects involve decisions concerning territory, infrastructure, investment, regulation, and the distribution of benefits and costs, and such decisions are rarely neutral. A nature-oriented transition therefore requires decision-making processes that simultaneously integrate environmental, economic, and social criteria, otherwise the expansion of renewable energy sources may be treated as something isolated from broader development processes.

This perspective can only be sustained in practice if governance mechanisms are established to integrate planning, coordination, monitoring, and risk management. The assessment conducted by the Brazilian Federal Court of Accounts (Tribunal de Contas da União, 2025) demonstrates that Brazil's energy transition involves different public policies and requires governmental coordination for its implementation. According to the diagnosis presented by the institution, governance and management components include the legal and regulatory framework, governmental structure, planning, coordination, risk management, and monitoring and transparency. Institutional innovation is relevant here because it enables energy, environmental, and territorial objectives to be addressed in an integrated manner rather than through separate processes.

Based on the dimensions discussed, Table 1 systematizes the main interfaces among energy transition, innovation, and environmental conservation, demonstrating how these elements can be integrated from a nature-oriented perspective.

Table 1. Dimensions of a nature-oriented energy transition and their interfaces with innovation

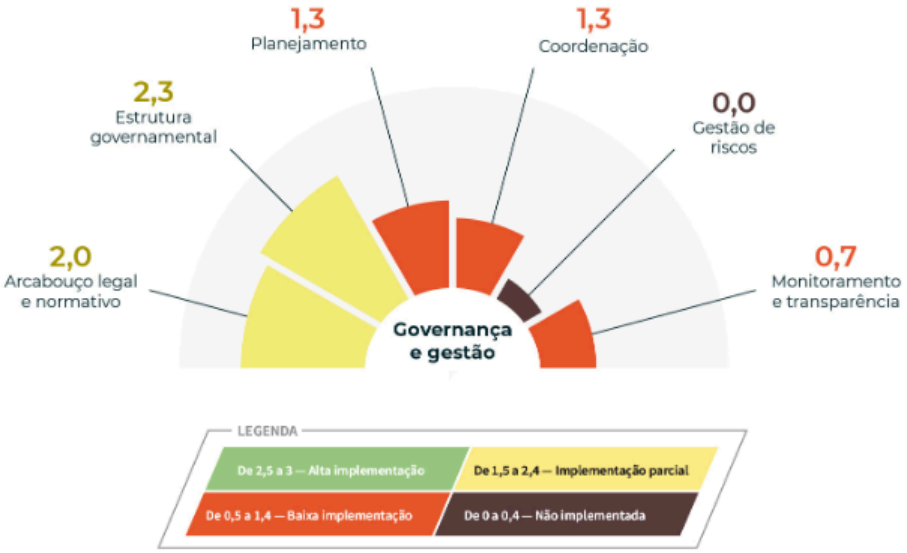
Dimension	Analytical Focus	Interface with Innovation	Contribution to a Nature-Positive Perspective
Energy transition	Transformation of energy production and consumption systems	Development and diffusion of renewable and low-carbon technologies	Reduction of dependence on fossil fuels and incorporation of environmental criteria
Technological innovation	New technologies, processes, and energy solutions	Solar and wind energy, energy storage, smart grids, and other low-carbon solutions	Reduction of impacts and greater efficiency in resource use
Institutional innovation	Public policies, regulation, planning, and governance	New mechanisms for coordination, monitoring, and management	Integration of energy, environmental, and territorial policies
Ecosystem conservation and restoration	Biodiversity protection and environmental restoration	Technological and organizational solutions oriented toward impact reduction	Maintenance of ecological integrity and restoration of affected areas
Regional development	Generation of income, employment, knowledge, and productive capacities	Development of productive chains, research, intellectual property, and skills development	Territorial distribution of the benefits of the transition and valorization of natural resources

Socio-environmental integration	Coordination among economic, social, and environmental dimensions	Participatory processes and social innovation	Greater compatibility among energy projects, territories, and communities

Source: Prepared based on Silva; Barros (2021); Cardoso; Camilo; Picolo (2024); Cataia; Duarte (2022); Corrêa (2021); Caracas; Gomes et al. (2026); Gomes (2025); Torres; Miguel; Martins (2024); Paixão; Abaide (2026); TCU (2025).

The institutional dimension becomes particularly relevant when examining the governance structure of Brazil's energy transition. The results presented by the Brazilian Federal Court of Accounts (Tribunal de Contas da União, TCU, 2025) indicate different levels of implementation across the components assessed, with relatively stronger performance in the legal framework and governmental structure and lower levels in planning, coordination, risk management, and monitoring and transparency. The diagnosis therefore demonstrates that the energy transition does not depend exclusively on technological availability, but also on the state's capacity to plan, coordinate, and monitor long-term policies.

Figure 1. Federal Government Governance and Management Structures for the Energy Transition



Source: Tribunal de Contas da União (2025), based on TC 020.606/2023-0, document 210, p. 40. Results refer to the assessment conducted in September 2024.

A joint reading of these dimensions makes it possible to understand that a nature-oriented energy transition requires a broader conception of innovation. It is not sufficient to produce renewable energy on a larger scale; it is also necessary to develop technological, institutional, and territorial capacities that enable energy expansion to be reconciled with the conservation and restoration of ecosystems. This orientation brings the energy transition closer to the concept of regenerative development, in which productive systems should be planned in consideration of their relationship with territories and ecological processes. In Northeastern Brazil, this approach provides an analytical basis for investigating innovation pathways capable of integrating energy, regional development, and environmental integrity (TCU, 2025).

2.2. Expansion Of Renewable Energy In Northeastern Brazil: Opportunities, Challenges, And Territorial Implications

The expansion of renewable energy in the Northeast is often presented as a direct consequence of the availability of solar and wind resources, and indeed it is. However, the analysis cannot stop

at this association. It is necessary to consider simultaneously the territorial, environmental, technological, and socioeconomic dimensions that shape these projects. As they are implemented, energy projects redirect investment flows, alter patterns of spatial occupation, and generate infrastructure demands that extend far beyond strictly energy-related issues. For this reason, the energy transition is addressed here as a process of territorial and productive reorganization, in which innovation, planning, and governance ultimately determine who receives the benefits and who bears the impacts of project implementation (Anjos et al., 2024; Guerrero, 2021).

Gehrke, Goretti, and Avila (2022 apud Vieira; Vieira, 2024, p. 06) emphasize that:

> *Brazil has great potential for developing technologies for energy generation from alternative renewable sources, owing to its high biodiversity and abundance of natural resources, which enable energy production in different forms, such as hydropower, solar, wind, and biomass, contributing to the sustainable diversification of the energy matrix and ensuring energy security. However, further studies are needed to implement more structured strategies and public policies capable of reducing the costs of implementing alternative renewable energy sources, since initial investments are currently high.*

In the Northeastern context, the expansion of solar and wind energy goes hand in hand with processes of technological innovation, the formation of new productive chains, and the reconfiguration of

infrastructure systems. However, it is important to be direct: increasing installed capacity does not, in itself, guarantee anything in distributive or environmental terms. What makes the difference is where projects are implemented, whether transmission infrastructure is available, under what conditions financing takes place, and whether there is coordination with local economic activities. These variables determine whether energy investment becomes regional development or remains confined to the project itself. Vieira and Vieira (2024) draw attention precisely to this issue: regional conditions determine the extent to which these energy sources can be harnessed and whether their expansion can be sustained over time.

The territorial dimension carries particular weight in this context because generating renewable energy at scale requires extensive areas, electrical connections, access routes, and a range of complementary structures, bringing projects into direct contact with existing land uses and populations. Sales (2020) had already identified the challenges and conflicts generated by renewable energy expansion in the Northeast, with the central point of the analysis being that the energy transition cannot be separated from the relationships among projects, territories, and social groups. Consequently, the implementation of new infrastructure must incorporate criteria for territorial planning, social participation, and ecosystem protection. Otherwise, there is a risk of replacing a fossil fuel source with another form of environmental pressure, merely shifting it elsewhere.

It is on the basis of these three dimensions that Table 3 was organized. It presents, side by side, the main opportunities,

challenges, and implications that the expansion of renewable energy brings to Northeastern Brazil.

Table 3. Opportunities, Challenges, and Territorial Implications of Renewable Energy Expansion in Northeastern Brazil

Dimension	Opportunities	Challenges and Implications
Solar energy	Expansion of renewable generation and diversification of the energy matrix	Need for territorial planning, electrical infrastructure, and land-use management
Wind energy	Expansion of electricity generation and integration into new productive chains	Territorial conflicts, changes in land-use dynamics, and need for environmental assessment
Technological innovation	Development of technologies, specialized services, and solutions for energy efficiency	Need to expand technological capacities and reduce economic barriers to the adoption of innovative solutions
Energy infrastructure	Expansion of grids, transmission systems, and regional integration	Pressures on the territory and need to reconcile infrastructure with environmental conservation
Socioeconomic development	Investments, job creation, and diversification of economic activities	Unequal territorial distribution of benefits and need for greater integration with local economies
Decarbonization	Reduction of dependence on carbon-intensive sources and alignment with climate targets	Transition costs, environmental risk management, and need for long-term business strategies

Territorial governance	Integration of energy, environmental, economic, and territorial policies	Institutional coordination, social participation, and conflict prevention
Environmental conservation	Possibility of associating energy expansion with ecosystem protection criteria	Risks of habitat fragmentation, pressure on natural resources, and need for conservation and restoration measures

Source: Prepared by the authors based on Anjos et al. (2024), Teixeira and Pessoa (2024), Guerrero (2021), Gomes et al. (2026), Vieira and Vieira (2024), Gehrke, Goretti, and Avila (2022), Sales (2020), Fortes (2024), and Arbache and Esteves (2023).

The expansion of renewable energy in the Northeast cannot be explained solely from the perspective of electricity supply. It is closely associated with changes in climate policies and with the pressure to decarbonize economic activities. Teixeira and Pessoa (2024) specifically examine this articulation between renewable energy and public policies addressing climate change in Northeastern states, and its effect on the discussion involves a shift in analytical framing. In practice, this requires energy planning, environmental policy, economic development, and territorial planning to be addressed as components of the same problem, which can no longer be sustained within a strictly sectoral framework.

This is the position expressed by Arbache and Esteves (2023, p. 3):

> *The proposal is associated with the commitments established under the Paris Agreement, which seek to address the effects of climate change and reduce greenhouse gas emissions. The practical implication was the establishment of ambitious targets for the decarbonization of economies and major compliance challenges for companies. However, this is not merely a compliance challenge. Carbon-intensive activities generate negative externalities that currently have organized markets capable of pricing them through offsetting credits, which grant their holders the right to pollute. The problem is that, depending on the prospective scenario for such markets, the price of carbon compensation may increase considerably in the coming years. Thus, the issue of decarbonization targets is twofold: environmental compliance and the management of environmental risks and liabilities.*

The geo-economic perspective adds another layer to the analysis, since the energy transition reconfigures interactions among natural resources, infrastructure, investments, and the location of economic activities. Guerrero (2021) demonstrates that energy changes have a territorial and geopolitical dimension, while Gomes et al. (2026) link the energy transition to the accessibility of strategic resources and the conditions for sustainable development. In the Northeast, this perspective makes it possible to understand the expansion of renewable energy not merely as an increase in energy supply, but as a movement capable of transforming the region's position within productive chains associated with a low-carbon economy.

The industrial dimension becomes particularly relevant when renewable energy supply is connected to the attraction of energy-intensive industries and the creation of new economic chains. Fortes (2024) links the energy transition to the possibilities for the reindustrialization of the Northeast, emphasizing the advantages arising from the regional availability of renewable sources. However, for this dynamic to result in more robust regional development, the expansion of generation must be accompanied by innovation, productive capacity building, infrastructure, and mechanisms that increase value retention within the territory, thereby avoiding a configuration that depends primarily on energy production and exports.

Thus, the expansion of renewable energy is a complex issue that intertwines infrastructure, innovation, and territorial organization. Gomes et al. (2026) and Fortes (2024) make it possible to relate energy transformation to changes in productive and technological processes, while Anjos et al. (2024) focus on the challenges and opportunities associated with renewable energy in the Northeast region of Brazil. The regional issue, therefore, lies in the capacity to transform the expansion of generation into economic and technological processes aligned with the specific characteristics of the territory.

Accordingly, the study of investments in energy infrastructure provides a tangible perspective for understanding how this expansion takes place in the Northeast. Table 4 presents data showing how financing provided by Banco do Nordeste to the infrastructure sector was distributed in 2023, including investments in photovoltaic generation, wind generation, sanitation, logistics,

distributed generation, telecommunications, gas distribution, power transmission, public lighting, and industrial infrastructure.

Table 4. Banco do Nordeste Financing for the Infrastructure Sector in 2023, by Area of Application

Área	Quantidade	Valor (R$)
Fotovoltaica	53	3.638.952.551,67
Eólica	45	3.287.198.463,19
Saneamento básico	15	2.710.707.065,01
Logística	5	1.292.555.694,30
GD fotovoltaica	130	655.753.907,62
Telecomunicações	4	371.862.000,00
Distribuição de gás	3	157.827.588,00
Transmissão de energia	1	137.557.686,40
Iluminação pública	1	13.700.000,00
Indústria	1	6.211.800,00
Total	258	12.272.326.756,19

Source: Fortes (2024)

Table 4 shows that financing reaches several sectors related to regional infrastructure, including direct investments in solar and wind energy sources. The coexistence of generation, transmission, distribution, logistics, and industry demonstrates that the energy transition is a matter of integrated infrastructure. From this perspective, financial investments cannot be measured solely by the

amount allocated to generation, but also by the maintenance of grids, productive activities, and services that support the consolidation of a diversified energy matrix. The analysis by Vieira and Vieira (2024) on sustainable regional renewable energy expansion also supports this perspective.

The expansion of renewable energy sources also requires particular attention to the environmental impacts associated with territorial occupation. Replacing emitting energy sources with low-carbon technologies during operation does not automatically eliminate impacts related to project implementation, the opening of access routes, the installation of transmission lines, and the transformation of natural areas. Teixeira and Pessoa (2024) emphasize the urgency of establishing synergy between energy and climate policies, while Sales (2020) demonstrates that challenges and conflicts are present in Northeastern Brazil. A nature-oriented transition therefore requires conservation standards to be integrated from the selection of areas through to the monitoring of ongoing projects.

Fortes (2024, p. 48) states:

> *Therefore, the combination of the powershoring strategy with the adoption of clean and renewable energy can be an effective solution for companies seeking to reduce their carbon emissions, cut operating costs, and differentiate themselves in the market. It is important for companies to consider these changes in the energy landscape when developing their sustainability and environmental responsibility strategies.*

When renewable generation is integrated with the location of industrial activities and the adoption of environmental criteria in business decisions, the energy transition acquires a new economic dimension. While Arbache and Esteves (2023) link Powershoring to decarbonization and economic growth, Fortes (2024) relates the supply of renewable energy to opportunities for the neo-industrialization of Northeastern Brazil. However, this articulation requires policies capable of connecting investments in energy with innovation, infrastructure, productive capacity building, and value addition, so that energy expansion can contribute to a regional development trajectory that is less dependent on the isolated exploitation of natural resources.

The analysis conducted here suggests that the expansion of renewable energy in Northeastern Brazil creates opportunities for diversification of the energy matrix, innovation, infrastructure development, and productive reorganization, while also imposing territorial, environmental, and socioeconomic challenges. According to Anjos et al. (2024), Vieira and Vieira (2024), and Gehrke, Goretti, and Avila (2022), natural and economic conditions are crucial to the expansion of renewable energy, while Guerrero (2021), Gomes et al. (2026), Teixeira and Pessoa (2024), Sales (2020), Fortes (2024), and Arbache and Esteves (2023) contribute to mapping this process across its territorial, climate, productive, and institutional dimensions. Thus, a nature-positive energy transition must be capable of reconciling the expansion of infrastructure, innovation, and regional development with the conservation and restoration of ecosystems.

3. METHODOLOGY

The positive nature transition cannot be explained by pulling a single thread. Focusing solely on energy, without considering the territory in which this energy will be deployed, the technology available to enable it, or the socioeconomic conditions of the populations that will coexist with it, overlooks precisely what gives meaning to the idea of a “nature-positive” transition. In the Brazilian Northeast, this requirement becomes concrete: the expansion of renewable energy sources in the region tends to intersect with processes of innovation and forms of regenerative development, which implies simultaneously considering the conservation of ecosystems that remain preserved and the restoration of those that have already been degraded. Hence the relevance of this study: understanding these relationships requires procedures consistent with the complexity of the phenomenon rather than procedures that reduce it to something easier to measure.

Regarding the research approach, this study is qualitative, with an exploratory and descriptive character. The choice of a qualitative approach is not merely a matter of classification: this approach occupies an established position in scientific research because it enables the interpretation of phenomena within their contexts, with attention to meanings, relationships, processes, and specificities that cannot be adequately captured through numerical measurement. This choice entails a trade-off, as it relinquishes statistical generalization in favor of the possibility of interpreting the phenomenon within its context, thereby enabling an integrated examination of the different dimensions of the energy transition and their relationships with innovation, territory, and nature, rather than treating them in isolation.

> *Qualitative research considers that there is a dynamic relationship between the real world and the subject, that is, an inseparable connection between the objective world and the subject's subjectivity that cannot be translated into numbers. The interpretation of phenomena and the attribution of meanings are fundamental to the qualitative research process. This approach does not require the use of statistical methods and techniques. The natural environment is the direct source for data collection, and the researcher is the key instrument. Such research is descriptive. Researchers tend to analyze their data inductively. The process and its meaning constitute the primary focus of the approach. In the qualitative approach, the research environment serves as the direct source of data. The researcher maintains direct contact with the environment and the object of study, requiring more intensive fieldwork. In this case, issues are investigated within the environment in which they occur, without any intentional manipulation by the researcher (Prodanov; Freitas, 2013, p. 71).*

The exploratory character proved appropriate for the investigation because it facilitated the conceptual organization of a topic involving the convergence of energy transition, innovation, environmental conservation, and regenerative development. According to Gil (2019, p. 41), "exploratory research is indicated when the object still requires greater theoretical delimitation or when the aim is to establish conceptual foundations for more in-depth analyses." In parallel, "the descriptive character is manifested in the intention to present and interpret characteristics, relationships, and economic implications

associated with the expansion of renewable energy, without establishing strict causal relationships," according to the definition presented by Lakatos and Marconi (2020, p. 22).

For the development of the investigation, two research procedures were employed: a literature review and documentary research. The literature review constitutes a relevant procedure for science because it enables systematic engagement with previously produced knowledge, identification of theoretical perspectives, recognition of convergences and divergences among studies, and establishment of the conceptual basis required to interpret the object (Sousa; Oliveira; Alves, 2021). In this study, it was based on the analysis of dissertations, scientific articles published in scientific events and journals, book chapters, and books related to energy transition, innovation, renewable energy, ecosystem conservation, and regenerative development. Documentary research, in turn, expands this basis by incorporating institutional documents and reports produced by organizations operating in the energy, environmental, economic, and public oversight fields (Salge; Oliveira, 2021).

The documentary research analyzed the following documents: International Renewable Energy Agency (IRENA), *World Energy Transitions Outlook 2022*; CEPAL, *Energy Transition and Sustainable Development in Latin America*; Tribunal de Contas da União, *Maturity of Public Policies for the Energy Transition in Brazil*; Banco do Nordeste do Brasil, institutional information; and World Wide Fund for Nature (WWF) and The Biodiversity Consultancy, *Nature-safe Energy: linking energy and nature to tackle the climate and biodiversity crises* (Salge; Oliveira, 2021).

The use of these materials made it possible to contrast the scientific literature with institutional documents and reference reports, fostering a contextualized interpretation of policies, guidelines, strategies, and relationships among energy, development, and nature. The combination of the two procedures proved appropriate to the purpose of the study because it enabled the articulation of systematically organized academic production with documentary evidence, thereby reinforcing the interpretive coherence and analytical consistency of the study (Salge; Oliveira, 2021).

FINAL CONSIDERATIONS

The nature-positive energy transition constitutes a research and intervention agenda that extends beyond the replacement of fossil fuels with renewable sources, as it requires transformations in energy systems to be articulated with biodiversity conservation, ecosystem restoration, and the socio-environmental quality of territories. In the Brazilian Northeast, this approach assumes particular relevance given the expansion of renewable energy and the need to reconcile technological innovation, economic development, territorial planning, and ecological integrity. In this regard, the research demonstrated that the energy transition can be conceived not only as a decarbonization strategy but also as an opportunity to redirect development patterns toward more balanced relationships among energy, society, the economy, and nature.

Considering the general objective and the three specific objectives established, it can be concluded that all were achieved throughout the research process. The general objective was fulfilled by demonstrating that innovation associated with the energy transition

can contribute to a regenerative development model in the Northeast, provided that the expansion of renewable energy is accompanied by criteria for ecosystem conservation, restoration, and valorization. The first specific objective was addressed through the analysis of the relationships among energy transition, innovation, and environmental conservation; the second through the discussion of the territorial, environmental, technological, and socioeconomic challenges and opportunities associated with renewable energy expansion; and the third through the systematization of strategies capable of bringing energy infrastructure, innovation, and socio-ecological regeneration closer together.

In the first topic of the theoretical framework, it was demonstrated that the energy transition is multidimensional in nature and depends on the articulation of technological innovation, public policies, regulation, investments, and transformations in production systems. The analysis also showed that the nature-positive perspective broadens the scope of the transition by shifting attention from a logic focused exclusively on emissions reduction toward an approach that simultaneously considers climate, biodiversity, and ecosystem functioning. Thus, innovation is understood as an instrument for reorganizing the relationships among energy production, land use, and environmental conservation.

In the second topic of the theoretical framework, it was found that the expansion of renewable energy in the Northeast combines favorable conditions for diversifying the energy mix and stimulating regional economic activity, while also involving challenges related to land occupation, environmental impacts, implementation costs, infrastructure, and the distribution of benefits. The analysis therefore

demonstrated that the expansion of renewable generation does not, in itself, produce a sustainable transition. Its outcomes depend on the forms of planning, siting, governance, social participation, and management adopted for energy projects, so that energy and economic gains are not dissociated from the ecological and social conditions of the territories.

In the third topic of the theoretical framework, it was demonstrated that regenerative development offers a perspective capable of broadening the outcomes of the energy transition by articulating technological innovation, social innovation, nature-based solutions, the restoration of degraded areas, territorial planning, and collaborative governance. The research made it possible to understand that renewable energy projects can be structured to generate benefits that extend beyond impact reduction by incorporating conservation actions, ecological restoration, community participation, socio-environmental monitoring, and integration with local productive activities. This articulation supports a conception of development in which energy, the economy, society, and nature are treated as interdependent dimensions.

As a contribution, the article systematizes an integrated approach to understanding the energy transition in the Brazilian Northeast based on the relationship between innovation and regenerative development, bringing together dimensions that are frequently analyzed separately. For future research, empirical studies on specific renewable energy projects are recommended, assessing indicators of biodiversity, ecological restoration, territorial value generation, community participation, and the distribution of socioeconomic benefits. Comparative investigations across territories, technologies, and governance models are also relevant, as

they can determine, in different contexts, the conditions under which the expansion of renewable energy can effectively generate positive outcomes for nature and communities.

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