

## **The MERCOSUR-EU Agreement and Infrastructure for the Energy Transition in Ceará: Challenges and Opportunities**

Spec. André Luiz Barros de Oliveira<sup>1</sup> <https://orcid.org/0000-0002-2838-4208>;

M. Sc. Alcides Feitosa Neto<sup>2</sup> <https://orcid.org/0009-0006-3749-3509>,

<sup>3</sup> Spec. Bertrand Ferreira Rodrigues <https://orcid.org/0009-0006-9716-9073>,

M. Sc. Cleilson Coutinho da Silva<sup>4</sup> <https://orcid.org/0009-0005-6952-6355>,

Spec. Evandro de Menezes Araújo<sup>5</sup> <https://orcid.org/0009-0003-0246-2460>,

Spec. Fabiano César de Oliveira Rocha<sup>6</sup> <https://orcid.org/0009-0002-2451-1828>,

M. Sc. Jeronimo Freire da Silva<sup>7</sup> <https://orcid.org/0009-0005-9355-0638>,

Spec. José Ferreira Mota Filho<sup>8</sup> <https://orcid.org/0009-0005-9355-0638>,

Spec. José Nabuco Ribamar Neto<sup>9</sup> <https://orcid.org/0009-0001-4648-531X>,

Spec. Josy Fonteles Ribeiro da Silva<sup>10</sup> <https://orcid.org/0009-0001-2569-2619>

M. Sc. Márcio Carneiro Barbosa<sup>11</sup> <https://orcid.org/0009-0003-8290-1127>,

Rickardo Léo Ramos Gomes<sup>12</sup> <https://orcid.org/0000-0001-6101-9571>;

<sup>1</sup> Postgraduate in MBA in Renewable Energy Management (IEL/FBUNI);

<sup>2</sup> Master's degree in Economics from the Federal University of Ceará; <sup>3</sup> Postgraduate Degree in Project Management – FACUMINAS; <sup>4</sup> Master's Degree in Science and Mathematics Teaching – Federal Institute of Education, Science, and Technology (IFCE); <sup>5</sup> Postgraduate in MBA in Renewable Energy Management (IEL/FBUNI); <sup>6</sup> Postgraduate in MBA in Renewable Energy Management (IEL/FBUNI); <sup>7</sup> Master's Degree in Mechanical Engineering from the Federal University of Rio Grande do Norte; <sup>8</sup> Postgraduate in MBA in Renewable Energy Management (IEL/FBUNI); <sup>9</sup> Postgraduate in MBA in Renewable Energy Management (IEL/FBUNI); <sup>10</sup> Postgraduate in MBA in Renewable Energy Management (IEL/FBUNI); <sup>11</sup> M. Sc. in Military Sciences – Army Command and General Staff School; <sup>12</sup> Doctorate in Biological Sciences - FICL; Master's in Phytotechnics - Federal University of Ceará;

Corresponding Author: Rickardo Léo Ramos Gomes

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### **ABSTRACT**

Energy transition is essential for ecological sustainability and global economic progress, focusing on replacing non-renewable energy sources with clean and renewable alternatives. In the context of Ceará, a Brazilian state with substantial potential for solar and wind energy production, the necessary infrastructure for this transition encounters both challenges and opportunities. This study addresses the issues related to the implementation of energy infrastructure in Ceará, examining the implications of the MERCOSUR-EU Agreement and the technical and financial barriers affecting the progress of the state's energy transition. The methodology adopted in this research follows a qualitative approach, emphasizing its critical relevance to scientific inquiry, particularly in fields that deal with complex processes and dynamic phenomena such as energy transition. Two fundamental methods were employed to conduct this study: literature review and documentary research, both of which are crucial for advancing scientific knowledge. The general objective of this study is to analyze the infrastructure required for the energy transition in Ceará, identifying the challenges and opportunities associated with sustainable development in the state, with a focus on the impact of the MERCOSUR-European Union Agreement and the technical and economic issues related to the implementation of renewable energy. Ultimately, the evaluation of the MERCOSUR-European Union Agreement highlighted the importance of international partnerships for improving Ceará's energy infrastructure by enabling technology transfer, investments, and expertise. However, the findings also underscored the necessity of more robust integration among various governmental levels and involved sectors to overcome the barriers posed by technical and economic constraints.

**Keywords:** *Ecological Sustainability; Energy Transition; Technology Transfer; International Partnerships.*

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## I. INTRODUCTION

Energy transition is one of the essential pillars for addressing climate change and building a more sustainable future. The shift from fossil fuels to renewable energy sources, such as solar and wind power, is a global strategy to reduce greenhouse gas emissions and promote the responsible use of natural resources.

In Brazil, regions like Ceará stand out for their significant potential to generate energy from renewable sources, strategically positioning themselves for the development of energy infrastructure aimed at transition. However, changing the energy matrix does not occur without obstacles. Despite its considerable potential for solar and wind energy production, Ceará faces structural challenges that hinder the establishment of a robust and efficient energy infrastructure.

Assessing the technical and economic obstacles—such as financing demands, workforce development, and opposition from certain groups—is essential to understanding the barriers that delay progress in the state’s energy transition. Moreover, the recent MERCOSUR-European Union agreement opens new avenues for global collaboration and technology transfer, which could present a significant opportunity for Ceará. This study aims to analyze the energy transition landscape in Ceará, emphasizing the governmental policies and local actions driving this transformation.

Additionally, it examines the implications of the MERCOSUR-EU pact for the development of energy infrastructure in the state, focusing on the opportunities and challenges presented. By addressing the primary technical and economic challenges the state faces, this study provides a comprehensive assessment of the current situation and proposes strategies to overcome identified barriers, supporting Ceará’s energy transition progress.

The methodology adopted in this research follows a qualitative approach, highlighting its critical relevance for scientific inquiry, particularly in fields dealing with complex processes and dynamic phenomena such as energy transition. Two fundamental methods were employed: a literature review and documentary research, both essential for advancing scientific knowledge.

The general objective of this study is to analyze the infrastructure required for Ceará’s energy transition, identifying challenges and opportunities related to sustainable development in the state, with a focus on the impact of the MERCOSUR-European Union Agreement and the technical and economic aspects of implementing renewable energy.

The specific objectives planned are as follows: 1. Examine the current state of Ceará’s energy matrix, highlighting the contribution of renewable sources such as solar and wind power, and discuss public policies and local initiatives driving the state’s energy transition. 2. Analyze the opportunities and challenges that the MERCOSUR-European Union Agreement presents for the development of Ceará’s energy infrastructure, particularly in technology, investments, and knowledge transfer. 3. Assess the main technical and economic challenges in implementing infrastructure for Ceará’s energy transition, including financing issues, professional training, and stakeholder resistance.

This article is structured into four main sections. The Introduction presents the research context and objectives, emphasizing the importance of Ceará’s energy transition. The Material and Methods section describes the qualitative approach adopted, the research procedures utilized—such as literature review and documentary research—and the importance of combining these methodological strategies. The Theoretical Framework discusses, in three subsections, the context of Ceará’s energy transition, the implications of the MERCOSUR-EU Agreement for energy infrastructure, and the technical and economic challenges in implementing this infrastructure. Finally, the Conclusions synthesize the research findings, highlighting their contributions to understanding Ceará’s energy infrastructure and suggesting directions for future research.

## II. MATERIAL AND METHODS

The methodology employed in this study follows a qualitative approach, emphasizing its vital relevance to scientific research, particularly in fields that deal with complex processes and dynamic phenomena, such as energy transition (Sousa & Santos, 2020).

Qualitative investigation is notable for its ability to provide a detailed understanding of specific contexts, enabling researchers to explore perceptions, experiences, and meanings that quantitative techniques might fail to capture (Sousa & Santos, 2020).

This perspective has played a crucial role in global science by allowing for a more comprehensive view of social, economic, and environmental issues. It offers an in-depth and meticulous evaluation of the processes under analysis, such as the progress and challenges of energy infrastructure in Ceará. To execute this study, two

fundamental methods were employed: a literature review and documentary research, both of which are critical to the advancement of scientific knowledge.

The literature review focused on notable scientific works discussing topics related to energy transition, infrastructure, public policies, renewable energies, and sustainable development. This method facilitated a critical evaluation of existing research, identifying gaps in knowledge, assisting in the creation of a robust reference base, and providing a comprehensive view of the current state of investigation in this area. The bibliographic analysis also enabled comparisons among various methodologies and theoretical approaches, reinforcing existing contributions (Cavalcante & Oliveira, 2020).

On the other hand, the documentary research centered on analyzing relevant documents from global, national, and state-level contexts. It examined reports from international organizations, official documents from the governments of Brazil and Ceará, as well as public policy actions directed toward sustainable energy (Piana, 2019).

This approach is crucial for understanding the guidelines, agreements, and strategies that shape energy practices and policies, offering a precise and contemporary perspective on scenarios impacting Ceará's energy transition. Documentary research, by providing direct access to formal texts and documents, offered an empirical foundation for evaluating applied policies. Additionally, it contributed to understanding the processes that might simplify or complicate the implementation of the required energy infrastructure. The combination of qualitative methodology with literature review and documentary research strengthens the chosen methodological strategy (Piana, 2019).

By integrating these methods, this study achieved a broad and detailed perspective, enabling the investigation of not only prior theories and research but also documented practices and policies. This integration renders the findings more robust and relevant. The convergence of these methodologies is highly significant for the advancement of global scientific research, offering a more detailed and contextualized analysis essential for addressing complex issues such as energy transition.

### **III. THEORETICAL FRAMEWORK**

The theoretical framework of this article addresses three critical aspects essential for understanding the infrastructure required for Ceará's energy transition. The first subsection explores the context of energy transition in the state, focusing on its current energy matrix and the public policies driving sustainability efforts. The second subsection examines the implications of the MERCOSUR-EU Agreement, highlighting opportunities for technological collaboration and investments in energy infrastructure. Finally, the third subsection discusses the technical and economic challenges in implementing this infrastructure, including issues related to financing, workforce training, and resistance to change.

#### **3.1 Energy Transition Context in Ceará**

The state of Ceará is located in the northeastern region of Brazil. Due to its proximity to the Equator, sunlight incidence is nearly perpendicular to the surface, resulting in higher temperatures (typically above 20°C) compared to higher latitudes (further south). These conditions provide permanent advantages for the technical exploitation and economic use of photovoltaic solar energy (Barbosa & Gomes, 2024). Furthermore, according to the Brazilian Wind Energy Association, the state ranked fifth nationally in wind energy generation in 2022, with a total of 7.06 TWh (ABEEólica, 2022).

Given these aforementioned potentials, Ceará's energy transition has been consolidated as a strategic process for the state's sustainability and economic development. Currently, Ceará's energy matrix comprises 39% thermal generation and 60% renewable sources, predominantly solar and wind. The state hosts 159 operational projects, with a total installed capacity exceeding 5.2 gigawatts (GW), including 3.2 GW from renewable sources and 2 GW from thermal sources (Benvindo, 2024; Ceará, 2024a; Ceará, 2024b).

Recently, Ceará has emerged as a hub for renewable energy, attracting significant investments and promoting public policies that encourage the expansion of clean energy sources. The state leads the Northeast region in distributed micro and mini-energy generation, with 76 operational wind farms totaling 1,937 MW (Ceará, 2024a; Ceará, 2024b). A cooperation agreement between MERCOSUR and the European Union, signed in December 2024, establishes measures to promote international trade and contribute to sustainable development. This agreement is projected to increase the GDP of MERCOSUR countries, including Brazil, by \$12 billion, while also significantly reducing customs duties, fostering economic integration, and strengthening sustainable production chains (Luciano, 2020; IEMA, 2023; Brazil, 2024).

In the context of Ceará, the MERCOSUR-European Union agreement may further stimulate the energy transition, attract investments in the renewable energy sector, and promote the adoption of cleaner technologies. Additionally, the state has implemented public policies focused on sustainability, such as the National Green Hydrogen Policy, aimed at increasing the share of green hydrogen in the state's energy matrix and reducing greenhouse gas emissions (EY, 2023; Ceará, 2024). These initiatives reflect Ceará's commitment to energy

transition, aligned with global trends and international policies that promote sustainability and economic development through renewable energy sources (EY, 2023; Silva & Braga, 2024).

### 3.2 Implications of the MERCOSUR-EU Agreement for Energy Infrastructure

Sustainable Development Goal (SDG) 7 (Affordable and Clean Energy) aims, by 2030, to strengthen international cooperation to facilitate access to research and clean energy technologies, including renewables, while promoting investment in energy infrastructure (UN Brazil, 2015). In alignment with SDG 7, the recent MERCOSUR-European Union agreement is significant for the development of energy infrastructure in Ceará. Signed in 2023, this agreement represents an important strategic alliance that seeks to strengthen commercial, technological, and investment ties between the two regions, focusing on areas such as renewable energy and sustainability. With its vast potential for solar and wind energy production, Ceará emerges as a key state to capitalize on the opportunities presented by this international partnership. Investments in energy infrastructure driven by this agreement could accelerate the energy transition in the state, reinforcing its position as a renewable energy hub (Brazil, 2024b; Messias, 2024).

Contributing to decision-making processes at both federal and state levels, the MERCOSUR-EU strategic energy partnership in Ceará aligns with the National Hydrogen Program (PNH2) of Brazil’s Ministry of Mines and Energy (MME). This program establishes international cooperation for the technological and market development of hydrogen production and energy use (Brazil, 2021). One of the main opportunities offered by the agreement in Ceará is technological cooperation. The European Union has made significant progress in clean energy technologies and innovative solutions, such as the production and storage of green hydrogen. The exchange of technology and know-how through strategic partnerships can accelerate the adoption of new energy solutions in Ceará, thereby improving the efficiency and sustainability of local infrastructure. Additionally, integrating advanced technologies can facilitate the modernization of existing facilities and the construction of new renewable energy plants (Brazil, 2024b).

Another critical aspect of the MERCOSUR-EU agreement is the potential for investments in energy infrastructure. The European Union, through its financing and investment mechanisms, could significantly contribute to expanding Ceará’s renewable energy infrastructure. Large-scale projects, such as solar and wind farms, could benefit from European funds aimed at increasing clean energy production and distribution capacities within the state. This investment flow has the potential to create new jobs and stimulate local economic development. Furthermore, knowledge transfer presents a strategic advantage for Ceará (Stojkoski, Koch, & Hidalgo, 2023; Araujo, 2024; Brazil, 2024b).

The European Union has extensive experience in implementing public policies focused on energy transition and sustainability. Sharing best practices and public policies can help create a more favorable regulatory environment for renewable energy in Ceará. Additionally, education and training programs for renewable energy professionals could be implemented, contributing to the development of a highly qualified workforce to meet the sector’s growing demands (Araujo, 2024). Table 1 presents examples of potential partnerships that Ceará could establish to fully leverage the expertise of European countries with economic ties to the EU.

Table 1 – Potential Strategic Partnerships

Country	Program	What it offers
Portugal	Portugal 2030	<ul style="list-style-type: none"> <li>- Subsidies and Funding: Direct financial support for innovative projects in renewable energy, such as solar and wind farms.</li> <li>- Tax Incentives: Tax benefits for companies investing in green technologies and energy efficiency projects.</li> <li>- Research and Development: Funding for R&amp;D in new clean technologies, promoting innovation and competitiveness in the Portuguese energy sector.</li> </ul>
United Kingdom	Planetary	Production of bioplastics and composite materials from agricultural waste, aiming to replace conventional plastics and reduce plastic pollution. <i>(Investments Received: Approximately €15 million, with support from private investors and EU innovation programs.)</i>
France	Heliogen	Solar energy technology concentrated to generate industrial heat at high temperatures, electricity, and clean fuels, using artificial intelligence to enhance efficiency. <i>(Investments Received: Around €30 million, including funding from private investors and EU support programs.)</i>
United Kingdom	Sylvera	Artificial intelligence platform that evaluates and monitors the effectiveness of carbon offset projects, ensuring the integrity and positive impact of sustainability initiatives. <i>(Investments Received: Over €10 million, with support from private investors and EU innovation funds.)</i>
Germany	Rivus	Advanced water management systems that utilize IoT and data analytics to optimize water use in environmental and urban settings, promoting water conservation and efficiency. <i>(Investments Received: Approximately €12 million, with funding from EU programs and private investors.)</i>

Source: Araujo (2024)

Adapting Ceará's energy matrix to the standards and requirements of the European Union will demand significant efforts in terms of adaptability and alignment with local policies. Differences in regulations and the need for consensus between parties may hinder the effective implementation of the project. Furthermore, the impact of economic and political fluctuations within MERCOSUR could affect investment stability and the continuity of established partnerships.

Quadro 2 - Opportunities and Challenges of the MERCOSUR-EU Agreement for Energy Infrastructure Development in Ceará

Opportunities	Challenges
<b>Technological Cooperation:</b> The agreement can promote joint research initiatives and the development of advanced technologies in renewable energy, particularly in solar and wind energy, aligning with Ceará's natural advantages.	<b>Regulatory Alignment:</b> Differences in energy regulations and standards between MERCOSUR and the EU could present challenges in integrating Ceará's energy infrastructure with EU frameworks.
<b>Investment:</b> The agreement opens avenues for European investments in energy infrastructure projects in Ceará, accelerating the transition to renewable energy sources and modernizing energy distribution systems.	<b>Economic and Political Instability:</b> Fluctuations in economic conditions and political situations in both the EU and MERCOSUR countries could impact the stability and continuity of investments and partnerships.
<b>Knowledge Transfer:</b> Collaboration on capacity-building programs, training, and knowledge exchange between the EU and Ceará could foster the development of human capital and the establishment of a skilled workforce in the renewable energy sector.	<b>Market Integration:</b> The integration of Ceará's energy market with the European Union's energy market could require significant infrastructural adjustments, which may be costly and time-consuming.

Source: Themoteo (2020)

Table 2 clearly summarizes the main opportunities and challenges that the MERCOSUR-EU agreement may bring to Ceará's energy infrastructure. While collaboration in technology, investments, and knowledge transfer can drive the renewable energy sector, issues such as regulatory alignment and market integration require attention to ensure a successful energy transition (Themoteo, 2020).

### 3.3 Technical and Economic Challenges in Implementing Energy Infrastructure

The establishment of energy infrastructure for the transition in Ceará faces several technical and economic obstacles that require unified and sustainable solutions. Among the technical challenges, there is a notable need to adapt the local electrical infrastructure to accommodate the increasing share of renewable sources, such as solar and wind power, which, despite their potential, exhibit fluctuations and variability (Ey, 2023; Caledônio, 2024).

It is crucial to incorporate emerging technologies, such as energy storage systems and smart grids, to enhance the distribution and utilization of the produced energy. Expanding the energy transmission and distribution network also represents a significant technical challenge, as most renewable sources are located in remote areas, requiring efficient systems to deliver energy to urban centers (Ey, 2023; Caledônio, 2024).

The Paris Agreement, one of the key documents related to global warming and energy transition, underscores the critical need for international cooperation on climate issues by promoting the reduction of technological and financial inequalities between countries in the Global South and Global North, including actions such as information sharing and strengthening R&D (FKA, 2022).

This document, recognized by the international community, aligns with the challenges faced in Ceará in terms of incorporating emerging technologies, which could benefit from the MERCOSUR-EU Agreement. From an economic perspective, one of the greatest challenges is financing large-scale renewable energy projects, which demand substantial capital for the construction and operation of solar and wind power plants. The difficulty in financing renewable energy infrastructure projects in Ceará is heightened by the need for robust public policies that promote private investment and help mitigate associated risks (Ramos et al., 2022; Ey, 2023; Caledônio, 2024).

It is essential to establish financial mechanisms, such as advantageous credit lines and government guarantees, to attract investments and ensure the economic sustainability of these projects. Moreover, it is critical to consider the costs of maintaining and operating emerging technologies, which can be high, particularly during the initial implementation phase (Ramos et al., 2022; Ey, 2023; Caledônio, 2024).

Another significant challenge is professional training, as the energy transition requires a highly specialized workforce in emerging technologies, such as the installation of photovoltaic systems, wind turbines,

and energy storage solutions. Training qualified professionals demands a stronger connection between the education system and the private sector, focusing on technical courses and training programs (Menezes, 2024).

Additionally, with the approval of the regulatory framework for offshore wind farms, Ceará has a significant opportunity to become a leader in implementing these projects in Brazil. Ceará accounts for approximately 20% of the projects awaiting environmental licensing, with an expected productivity nearly 60% above the global average. Ceará is a pioneer in this energy generation market, and Brazil could become one of the world's largest players in green hydrogen production. One of the main obstacles to advancing offshore wind energy is establishing a reliable supply chain capable of meeting the complex specifications of such projects. The logistics activity must ensure coordination between the planning stages and guarantee financial competitiveness compared to other energy sources. During the implementation phase, all assembly and installation processes occur offshore, involving specialized vessels for each operation. These include tugboats to transport platforms, ROVs for anchoring and cabling support, and crane vessels for lifting parts and assembling turbines on the platforms (Weber, 2020; Agência Dino, 2022; Agência Cenário Energia, 2024).

Resistance from certain stakeholders, such as conventional energy companies and even the local population, can pose a considerable barrier. This occurs because renewable technologies are often perceived as innovative and disruptive, raising uncertainties about future benefits (Brasil, 2022).

The energy transition in Ceará also faces challenges related to regulation and governance. Aligning state and municipal laws with national and international standards is essential to ensure a regulatory framework conducive to renewable energy development (Brasil, 2022).

Collaboration among local, state, and federal governments is crucial to overcoming administrative and bureaucratic barriers that may delay project execution. Additionally, fostering the participation of civil society and stakeholders in decision-making processes is critical to ensuring that the benefits of the energy transition are widely disseminated, preventing adverse effects on vulnerable communities (Ramos et al., 2022).

Assessing the technical and financial challenges in building energy infrastructure in Ceará highlights the complexity of this transition while also pointing to opportunities for a more sustainable energy future. The application of renewable energy in Ceará also involves significant safety considerations. Initially, the construction and operation of solar and wind farms must ensure the safety of workers and surrounding communities by implementing strict safety measures in both workplace environments and equipment transportation (Brando, 2023; Campos Junior, 2024).

The following Table 3 summarizes the main obstacles:

Quadro 3 – Technical and Economic Challenges

Technical and Economic Challenges	Description
<b>Grid Modernization</b>	Need to modernize the grids to integrate intermittent renewable sources, such as solar and wind energy.
<b>Integration of Renewable Technologies</b>	Technical challenges related to the integration of energy storage systems and smart grids.
<b>Project Financing</b>	Difficulty in attracting investments due to high initial costs and the lack of adequate financial mechanisms.
<b>Workforce Training</b>	Need to train a specialized workforce to handle new renewable energy technologies.
<b>Resistance to Change</b>	Cultural and economic barriers, especially among traditional energy sector stakeholders, who fear the transition to renewable sources.
<b>Maintenance and Operating Costs</b>	High costs, particularly in the early stages of implementing renewable energy infrastructures, such as solar and wind plants.
<b>Regulation and Governance</b>	Challenges related to adapting regulations and public policies to ensure a favorable environment for the implementation of renewable energies in Ceará.

Source: Benvindo (2024)

Moreover, issues related to digital security are gaining increasing importance, as smart grid infrastructures and energy storage systems rely on digital technologies that can be vulnerable to attacks. Furthermore, the modification of existing infrastructures and the implementation of new networks require a meticulous assessment of environmental risks, such as natural disasters, which may impact the operation of renewable energy sources (Brando, 2023; Campos Junior, 2024).

It should be emphasized that, in recent years, the Brazilian Northeast has emerged as a potential hub for renewable energy generation, particularly wind and solar power. However, a significant obstacle threatens to hinder the full realization of this potential: the lack of transmission line infrastructure. Despite substantial growth in wind and solar energy production in the region since 2014, the expansion of transmission lines has lagged behind, with an average growth of only 5%. The most critical transmission bottlenecks are located in areas with high-density renewable energy generation but insufficient infrastructure for energy distribution. Semi-arid regions in the Northeast, including parts of Bahia, Ceará, and Rio Grande do Norte, face severe challenges in this regard (Gaspar, 2024; Santana, 2024).

The opposition of certain segments of society can also present challenges related to social security and the protection of the rights of communities affected by the implementation of large-scale energy projects. Table 4 below summarizes the main security concerns associated with the introduction of renewable energy in Ceará:

Table 4 - Main Security Concerns Associated with the Introduction of Renewable Energy in Ceará

Security Issues	Description
Cybersecurity	The need for robust cybersecurity measures to protect smart grids and renewable energy systems from cyber-attacks.
Grid Stability and Reliability	Ensuring the stability and reliability of the energy grid during the integration of renewable sources like solar and wind, which are subject to variability.
Safety of Energy Storage Systems	Ensuring the safety of energy storage systems, such as batteries, which can present risks related to fire or chemical hazards.
Operational Safety	Ensuring that operational safety standards are met in renewable energy plants, especially in offshore wind and solar farms.
Environmental Safety	Minimizing the environmental impact of energy production and infrastructure, such as avoiding biodiversity loss or soil and water contamination during the construction of plants.
Disaster Preparedness	Developing contingency plans to respond to natural disasters (e.g., hurricanes, floods) that could damage energy infrastructure, especially for offshore and coastal systems.
Supply Chain Security	Addressing vulnerabilities in the renewable energy supply chain, ensuring that materials and components are sourced and transported securely.

Source: Brando (2023)

Table 4 highlights the main security challenges associated with the implementation of renewable energy in Ceará, addressing issues such as workplace safety, digital security, environmental security, and social security. It is essential to focus on these aspects to ensure that the transition to a renewable energy matrix occurs in a safe, efficient, and sustainable manner, mitigating adverse effects on both the environment and local communities (Benvindo, 2024).

#### IV. DISCUSSION AND CONCLUSION

The study conducted in this article fully achieved the goals initially established, providing a comprehensive assessment of the infrastructure required for the energy transition in Ceará. Through a qualitative method combining literature review and documentary research, we were able to investigate the challenges, opportunities, and consequences of Ceará's energy landscape from both local and global perspectives.

The approach used enabled an in-depth analysis of governmental policies, regional actions, and the technical and financial challenges associated with the implementation of renewable energy in the state. Among the study's main findings are: (1) the growing importance of renewable energy sources, such as solar and wind, in Ceará's energy transition scenario, positioning the state as a model of sustainable development for other states and nations in the region; and (2) the economic and technical obstacles facing local energy infrastructure, such as insufficient financing and the need for professional training, which must be overcome to ensure the full implementation of renewable energy projects in the state.

Additionally, the evaluation of the MERCOSUR-European Union agreement highlighted the relevance of international partnerships in enhancing Ceará's energy infrastructure by enabling technology transfer, investments, and knowledge sharing. However, it also underscored the need for more robust integration across different governmental levels and sectors involved to overcome the technical and economic constraints.

For future studies, a more detailed analysis of specific financing practices for renewable energy in Ceará is suggested, considering the role of both local and international financial entities. Furthermore, research on the impact of regional public policies on local communities would be valuable, examining how the energy transition affects both the environment and the quality of life of the inhabitants.

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