

The Contribution of International Logistics to Supporting the Renewable Energy Supply Chain in The State of Ceará

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ABSTRACT

International logistics plays a strategic role in the development of supply chains, especially in emerging sectors such as renewable energy. In the context of the state of Ceará, which stands out for its initiatives aimed at diversifying the energy matrix and expanding sustainable sources, logistical efficiency is essential for enabling the integration of global markets, reducing operational costs, and strengthening regional competitiveness. This article analyzes the contributions of international logistics to the renewable energy supply chain in Ceará, exploring the challenges faced, the available infrastructure, and opportunities for improvement within the sector. The methodology adopted involved a qualitative approach utilizing the research procedure known as bibliographic research. The main objective of this study is to analyze the contribution of international logistics to the integration and strengthening of the supply chain in the renewable energy sector in Ceará, identifying the logistical challenges, opportunities, and solutions that enhance the sustainable expansion of wind and solar energy generation and distribution in the region. The study concluded that currently existing services, particularly maritime services, involve transshipments at other ports located in the southern or southeastern regions of the country, resulting in long internal routes to be covered through available multi-modal services. This ends up increasing product costs, as the farther the product is from its consumption area, the higher the transportation cost. Therefore, establishing direct routes and services could significantly reduce costs, promoting greater efficiency in the transportation and distribution of goods.

Keywords: Renewable Energy; Logistics; Imports; Multi-modal Services.

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I. INTRODUCTION

The BP Energy Outlook (BP, 2020) indicates that the global energy system has historically been structured around fossil fuel sources, making it a significant emitter of carbon dioxide (CO₂) and other greenhouse gases (GHGs).

Decarbonization and global warming mitigation efforts focus on the challenge of restructuring countries' energy matrices and necessarily involve energy policy initiatives that support the dissemination of cleaner energy sources, such as renewable energy.

The transition to renewable energy sources has become a global priority, and the state of Ceará has emerged as a key player in this scenario. International logistics plays a crucial role in supporting and expanding the renewable energy supply chain, ensuring efficiency in the import/export of equipment and sustaining the sector's development.

According to Christopher (2016), international logistics involves the efficient and coordinated management of activities such as transportation, warehousing, inventory control, order processing, and information management to ensure the smooth flow of goods and services across global supply chains.

In the context of renewable energy, international logistics encompasses a range of activities aimed at optimizing the global flow of products and information. This optimization is crucial, as it involves the efficient movement of equipment, raw materials, and finished products between different countries and regions. Authors such as Christopher (2016) and Rodrigues et al. (2020) highlight the importance of logistics in supply chain management, emphasizing the need for effective integration and coordination.

Ceará's strategic location for renewable energy production, favorable climatic conditions, and geographical proximity to key potential consumer markets are significant advantages, but the effectiveness of these advantages depends on the quality of the logistics infrastructure. Studies by the Industry Portal (CNI, 2020) emphasize the importance of investments in ports, highways, and railways to enhance connectivity and reduce logistics costs.

The lack of adequate infrastructure can pose a barrier to the expansion of the renewable energy sector. Logistics infrastructure plays a critical role in the economic development and competitiveness of a region. In the case of Ceará, located in the Northeast region of Brazil, logistics infrastructure has been the focus of significant investments over the past decades, aiming to improve connectivity and facilitate national and international trade (ASTEFA, 2018).

Ceará's transportation infrastructure includes a combination of highways, railways, ports, and airports. Highways are essential for the land transport of goods, connecting the state to important production and consumption centers. Railways, though less developed, have been targeted for expansion and modernization projects to increase the efficiency of cargo transport (ASTEFA, 2018). Ceará's ports, such as the Port of Pecém and the Port of Fortaleza, play a crucial role in international trade, facilitating the movement of goods between the state and other countries. The Port of Pecém, in particular, has stood out as an important logistical hub in the Northeast region, with investments in infrastructure and the capacity to handle large cargo ships (ASTEFA, 2018).

However, despite advances in logistics infrastructure, the state of Ceará still faces challenges, such as the need to improve the quality of highways and railways, increase port efficiency, and enhance integrated logistics services (ASTEFA, 2018). Most of the components used in manufacturing renewable energy equipment are imported. International logistics plays a critical role in efficiently managing the transportation, storage, and customs clearance of these components.

Ballou (2017) highlights the need for logistics strategies that minimize costs and time in the importation of inputs. This academic article focuses on the strategic relevance of international logistics for advancing renewable energy in the state of Ceará. Considering the growing global interest in transitioning to more sustainable energy sources, it is essential to understand and improve the logistics chain that supports this expanding sector.

Ceará's potential in renewable energy is remarkable, especially in wind and solar energy, due to its favorable climatic conditions and vast areas available for the installation of wind farms and solar power plants. Therefore, it is crucial to explore this potential efficiently and sustainably. International logistics faces significant challenges in enabling the transportation of equipment and components necessary for renewable energy projects. Issues such as inadequate economic infrastructure, customs bureaucracy, and high logistics costs can hinder the competitiveness and efficiency of operations.

For the renewable energy sector in Ceará to reach its full potential and contribute effectively to the state and national energy matrix, it is vital to ensure an efficient, sustainable, and integrated logistics chain. This will not only reduce operational costs and increase competitiveness but also minimize the environmental impact of logistics activities. In addition to benefiting the companies and investors involved, the development of international logistics for the renewable energy sector in Ceará has the potential to drive regional economic development.

This occurs through job creation, generation of tax revenue, and promotion of innovation and sustainable growth. Thus, this academic article aims to highlight the importance of investigating the contribution of international logistics in meeting the needs of the renewable energy supply chain in the state of Ceará. The goal is to provide valuable insights for the development and/or improvement of this strategic sector.

Regarding the methodology, a qualitative approach was considered, employing the research procedure known as bibliographic research. The general objective of this research is to analyze the contribution of international logistics to the integration and strengthening of the supply chain in the renewable energy sector in the state of Ceará, identifying the logistical challenges, opportunities, and solutions that enhance the sustainable expansion of wind and solar energy generation and distribution in the region.

The specific objectives planned are as follows: To analyze the current logistics infrastructure in the state of Ceará and its capacity to support the renewable energy supply chain; To investigate the challenges faced by international logistics in importing equipment and components for the renewable energy sector in Ceará; To identify opportunities for improving the logistics of importing inputs for the renewable energy supply chain in Ceará; To propose strategies and recommendations to enhance international logistics in support of the renewable energy sector in the state of Ceará.

This article is organized into four sections. The first section is the introduction, which outlines the research objectives. The second section explains the methodological procedures developed to conduct the research. The third section presents a theoretical foundation that includes contributions from various sources addressing the same theme studied here. Finally, the fourth section elaborates on the concluding remarks, where the research findings are compiled, and new research suggestions are proposed to enhance the completed study.

II. MATERIAL AND METHODS

Regarding the methodology, a qualitative research approach was adopted, as noted by Minayo (2012), who states that qualitative research involves the organization, interpretation, understanding, and systematization of knowledge to enable the comprehension and apprehension of reality in its entirety. According to the author, qualitative research addresses specific issues by revealing a “world of meanings, beliefs, and attitudes, which corresponds to a deeper domain of relationships, processes, and phenomena that cannot be reduced to the operationalization of variables” (Minayo, 2012, p. 22).

To carry out this study, the bibliographic research method was adopted, consulting scientific works from the past eight years on international logistics and the renewable energy sector. Minayo (2012, p. 68) also highlights that “bibliographic research is a qualitative study, whose procedures are previously planned and aim to answer the research question, namely, the object and problem of the research.” Thus, bibliographic research primarily serves the intentional purpose of supporting scientific investigation.

According to Marconi and Lakatos (2003), the structure of bibliographic research involves the use of various document sources, requiring researchers to employ investigative procedures and handle materials such as publications (theses, books, monographs, articles, standalone publications), cartographic materials (maps, graphs), audiovisual media (interviews, lectures, films), as well as the written press (newspapers, magazines). These diverse resources demand significant attention from the researcher to maintain the scientific rigor of the investigation. The main scientific works that significantly contributed to this research were those of ASTEF (2018), Cavalcante (2024), and Picanço (2024).

III. THEORETICAL FRAMEWORK

This theoretical framework was organized into three (3) subtopics. The first addressed the role of international logistics. The second presented the main challenges of international logistics in the renewable energy sector. Finally, the third provided an assessment of the logistical infrastructure that directly impacts the renewable energy sector in the state of Ceará.

3.1 The Role of International Logistics

To achieve the goals outlined in the Paris Agreement, countries must conduct studies projecting energy demand and greenhouse gas (GHG) emissions under different levels of ambition. In emerging countries, the transformations required for a low-carbon scenario must align with socioeconomic development and access to mobility, considering a spectrum of mitigation options and the engagement of stakeholders (COPPE/UFRJ, 2022).

With the global environment on the brink of collapse, actions aimed at reducing socio-environmental impact have been devised by most political leaders and demanded by key international organizations, such as the United Nations (UN). Among the main decisions made by countries in a joint effort to promote a sustainable future for the planet is the commitment to achieve net-zero carbon dioxide (CO₂) emissions by 2050, relying exclusively on renewable energy sources (Ceará, 2022).

According to Jurandir Picanço, Energy Consultant at the Federation of Industries of Ceará (FIEC), Brazil stands out positively due to its abundant and cost-effective renewable energy resources, such as wind and photovoltaic solar power, as well as its technological capacity to produce and export green hydrogen. This advantage contrasts with countries like Japan, South Korea, and parts of Europe, which often face challenges in meeting energy transition demands (Picanço, 2024).

Given its strategic geographical position relative to these countries, Ceará plays a critical role in the global energy matrix transformation through the Pecém Port. According to data from the National Electric Energy Agency (ANEEL), wind and solar, the two main renewable energy sources, account for 53.6% of Ceará’s electricity matrix. Furthermore, Joaquim Rolim, coordinator of the Energy Core at FIEC, notes that Ceará will soon see 70% of its electricity matrix composed of renewable sources, with continuous improvements over the past few years, demonstrating progress in the right direction.

The Pecém Industrial and Port Complex (CIPP) stands as the centerpiece of Ceará’s port infrastructure supporting the renewable energy supply chain (ANEEL, 2022; Araújo, 2021). Data from a commercial intelligence study conducted by the International Business Center (CIN) of the FIEC highlight January 2024 as a period of growth for Ceará’s imports.

This growth is marked by sector diversification and the expansion of imported products. Notably, a 21.5% increase in Electrical Machines and Materials (HS2 85) led to imports totaling USD 74.45 million, driven by demand for photovoltaic cells from China, reflecting Ceará’s focus on renewable energy (Cavalcante, 2024). More detailed information is provided in Table 1 below:

Table 1 – Ceará’s Imports by Sector (HS2) Year-to-Date

SH2	Sectors	2024 FOB (US\$)	2023 FOB (US\$)	Annual Variation
27	Mineral fuels, mineral oils, and products of their distillation; bituminous substances; mineral waxes	75,033,724	55,742,878	34.6%
85	Electrical machinery and equipment, and their parts; sound recorders and reproducers; television image and sound recorders and reproducers, and their parts and accessories	74,446,336	61,251,477	21.5%
10	Cereals	19,779,224	21,691,595	-8.8%
84	Nuclear reactors, boilers, machinery, mechanical appliances, and parts thereof	16,553,181	15,128,166	9.4%
29	Organic chemicals	14,850,667	17,512,876	-15.2%
39	Plastics and articles thereof	7,321,721	10,971,041	-33.1%
73	Articles of iron or steel	5,731,596	1,925,217	197.7%
54	Synthetic or artificial filaments	5,126,634	5,171,458	-0.9%
68	Articles of stone, cement, asbestos, mica, or similar materials	4,155,337	9,945,999	-58.3%
31	Fertilizers	4,020,695	2,856,000	40.7%
	Other Sectors	38,643,670	61,856,537	-37.3%
	Total	265,662,785	263,787,809	0.7%

Source: Brazil (2024)

3.2 Main Challenges of International Logistics in the Renewable Energy Sector

International logistics in the renewable energy sector faces complex challenges that can directly affect the feasibility and scalability of projects. One of the main obstacles lies in supply chain management, often involving large and specialized components such as wind turbines and solar panels. These pieces of equipment require suitable transportation modes—primarily maritime, road, and air—adding complexity and cost to logistics, particularly in regions with inadequate infrastructure (Gomes et al., 2024).

Another significant challenge is compliance with international and environmental regulations. Each country has specific standards for the importation of equipment and the transportation of goods classified as sensitive. Moreover, growing concerns about sustainability demand that logistics operations minimize carbon emissions—a goal that can increase operational costs due to the adoption of sustainable technologies and practices (Silva et al., 2019).

Market volatility also poses considerable impacts. Currency fluctuations, supply chain disruptions, and global crises, such as pandemics and geopolitical conflicts, can lead to significant delays and unforeseen costs. To mitigate these challenges, it is crucial to adopt strategies that integrate tracking technologies, reliable partnerships, and robust logistical planning to achieve greater efficiency and sustainability in the renewable energy sector (Marcial & Pio, 2023).

3.3 Evaluation of the Logistical Infrastructure Impacting the Renewable Energy Sector in the State of Ceará

The state of Ceará has become one of the main centers for renewable energy production in Brazil, especially in the wind and solar energy sectors. However, the full development of the industry is intrinsically linked to the quality of the available logistical infrastructure.

Logistics is a key factor in the installation, operation, and maintenance of energy generation sites, as it involves the transportation of large equipment, such as wind farms and photovoltaic modules, which requires specialized knowledge of routes and customized logistical solutions. Despite its strategic location in Northeast Brazil, Ceará still faces challenges related to the capacity and efficiency of its ports, highways, and railways. For example, the Pecém port plays a central role in the logistics sector of the industry, serving as an entry point for imported equipment. However, operational bottlenecks and the need for greater integration with state highways could impact the flexibility of transportation to project installation sites (FIEC, 2021).

Another related aspect is the lack of railway infrastructure, which could reduce costs and provide more sustainable alternatives for transporting heavy cargo. Additionally, the expansion of the network to link wind and

solar farms to power substations creates a logistical and technical challenge that directly impacts the ability to move the amount of energy produced. Without this integration, the state's renewable potential risks being underutilized (Silva; Braga, 2024).

Investment in logistical infrastructure is necessary to optimize transportation, reduce operational costs, and increase the competitiveness of the renewable energy sector in Ceará. Solutions such as the modernization of the Pecém port, paving of strategic highways, and the integration of transportation modes can strengthen the state's role as a national reference in clean energy, tailored to the country's global needs for sustainability and efficiency (Ceará, 2023).

IV. DISCUSSION AND CONCLUSION

The research fully met its objectives, as the bibliographical investigation successfully addressed the key contributions of international logistics to the integration and strengthening of the supply chain in the renewable energy sector in the state of Ceará.

The study highlighted that for the renewable energy sector in Ceará to reach its full potential and contribute effectively to both the state and national energy matrices, it is crucial to ensure an efficient, sustainable, and integrated logistics chain. This will not only reduce operational costs and increase competitiveness but also minimize the environmental impact of logistical activities. In addition to benefiting the companies and investors involved, the development of international logistics for the renewable energy sector in Ceará has the potential to stimulate regional economic development.

The research also identified several areas that deserve special attention. For instance, it was noted that there are currently no direct air and sea routes connecting Ceará to the main Asian ports or airports, from where most of the raw materials and equipment for the renewable energy supply chain are shipped. Currently, existing services, especially maritime, involve transshipment at other ports located in the southern or southeastern regions of Brazil, resulting in long internal transportation distances via available multimodal services. This, in turn, increases the cost of goods, as the farther the product is from its consumption area, the higher its transportation costs. Therefore, establishing direct routes and services could significantly reduce costs, promoting greater efficiency in the transport and distribution of goods.

However, it is well understood that significant investments in infrastructure and services go beyond meeting market demands and depend on complex agreements and conditions between the public and private sectors. Given the breadth of the topic, a more in-depth analysis would require a new study focused on its various implications and possibilities.

Therefore, it is suggested that future studies further investigate the opportunities for logistical integration between Ceará and the main markets for raw materials and equipment for the renewable energy sector, particularly in Asia. Research that evaluates the impact of government policies focused on improving port, airport, and multimodal infrastructure, as well as the possibility of creating direct routes, could provide valuable information for strategic decision-making. Moreover, studies analyzing the economic, environmental, and social advantages of implementing a more effective international logistics system in the state could assist in the sustainable advancement of the sector and the development of more robust action plans.

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