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A Brief Reflection on the First Industrial Revolution in England (1760–1850) and the Energy Transition in Ceará with Green Hydrogen: An Analysis from Political, Economic, Social, and Scientific-Technological Perspectives

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Abstract:
Background: *This study compares and reflects on the key aspects of the First Industrial Revolution and the energy transition process in Ceará in the context of green hydrogen. It highlights the importance of history as a tool for developing a critical analysis of the past, shaping new perspectives in the present. Additionally, it seeks to identify similarities and differences between the two events, providing insights to support the development of green hydrogen in Ceará.*
Materials and Methods: *A qualitative approach was adopted to explore in depth the historical contexts involving England and contemporary Ceará. The research methodology consisted of a literature review, which involved consulting sources classified into two categories: (1) sources on the First Industrial Revolution and (2) sources on the energy transition scenario in Ceará with green hydrogen.*
Results: *The findings suggest possible actions to enhance the energy transition in Ceará, based on a critical analysis of the historical events of the 18th century.*
Conclusion: *By drawing parallels between the First Industrial Revolution and the ongoing energy transition in Ceará, this study provides a historical foundation for understanding the challenges and opportunities associated with green hydrogen development in the region.*
Keywords: *First Industrial Revolution; Critical Analysis; Energy Transition; Green Hydrogen.*

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I. Introduction

Humanity is rich in historical events and milestones that have profoundly and permanently shaped the course of various societies. The First Industrial Revolution, which took place in England (1760–1850), is a classic example. Its significance and magnitude were such that it positioned Europe as the first continent to introduce the factory system as a replacement for artisanal labor. Its consequences resonated globally, inspiring numerous countries to adopt its fundamental principles.

In contemporary times, another transformative event, soon to be recorded in the history of Ceará, is the energy transition process driven by green hydrogen (H_2 V). Its prospects extend beyond fostering the state's socioeconomic development; it has the potential to establish Ceará as a global provider of renewable energy, contributing to the decarbonization of the economy.

Although these two events may appear unrelated in time and space, understanding the key aspects of the first may still hold significant value today. Analyzing the political, economic, social, and scientific-technological contexts of that period could provide insights and contribute to a critical assessment of current strategies, either reaffirming or refining existing plans.

What lessons could the First Industrial Revolution offer for the current energy transition? Are there any similarities between what occurred in 18th-century England and what is happening in Ceará today? Can insights from the former inform and guide the latter?

Regarding the methodology, a qualitative approach was adopted. The study employed bibliographic and documentary research methods, drawing on national and international publications, reports, scientific articles, and online sources. Through the review and consolidation of these materials, a critical analysis of both historical and contemporary events was conducted.

The general objective of this study is to compare and reflect on the First Industrial Revolution and the energy transition in Ceará with green hydrogen. From these reflections, it aims to assess how the former could offer insights and contribute to the ongoing energy transition in the state.

The specific objectives are as follows: to explain how historical events can influence the present; to describe the key political, economic, social, and scientific-technological developments that shaped the First Industrial Revolution; to present, based on the same criteria, an overview of the current energy transition in Ceará with green hydrogen; and to identify potential contributions from the First Industrial Revolution to the contemporary energy transition.

This article is structured into four sections, providing a comprehensive analysis of the major developments in England and Ceará in the industrial and energy sectors, respectively. The first section, Introduction, presents the central theme of the study. The second section, Methodology, outlines the research approach adopted. The third section, Theoretical Framework, discusses the relevance of history and its potential lessons for the present, offers a description of major events in 18th-century England and contemporary Ceará, and explores how insights from the former could benefit the latter. Finally, the fourth section, Final Considerations, synthesizes the main findings, emphasizing how the First Industrial Revolution could serve as a reference for specific aspects of the energy transition in Ceará with green hydrogen.

II. Material And Methods

The approach adopted in this research was qualitative in nature, as the primary objective was to reflect on and compare the key milestones of the First Industrial Revolution with significant developments in the energy transition process in Ceará involving green hydrogen (H_2 V).

The qualitative approach is widely recognized in the scientific community for its ability to provide historical and contextual analyses, allowing for an assessment of the circumstances surrounding both the First Industrial Revolution and the ongoing energy transition in Ceará. Qualitative research focuses on the interpretation of complex phenomena, making it essential in fields that examine historical events of great significance in human history.

As Neves (1996), cited by Dias et al. (2024, p. 197), argues, "qualitative and quantitative methods are not mutually exclusive; on the contrary, they can be used complementarily, which enhances the reliability of research." The research procedure adopted was a literature review, an essential methodology for scientific knowledge construction, as it enables a critical and integrated analysis of existing information on a given topic.

According to Lakatos and Marconi (2017), a bibliographic review contributes to a broader understanding of the research object while also promoting the consolidation of well-founded approaches. For this review, research sources were carefully selected and classified into two main categories: (1) sources specifically related to the key events of the First Industrial Revolution and (2) sources concerning the energy transition process in Ceará with H_2 V.

This classification allowed for a more contextualized analysis, enabling the development of critical thinking regarding potential lessons from England that could be applied in Ceará. The review was conducted through an extensive examination of international organization reports, national and international publications, scientific articles, books, and online sources, ensuring a comprehensive perspective that reflects the most relevant contributions from the 18th century to the current context in Ceará.

III. Literature Review

This theoretical framework was structured into four subtopics. The first discusses the importance of History as a means of understanding the present. The second provides a brief retrospective of the First Industrial Revolution. The third examines the context of the energy transition in Ceará with green hydrogen (H_2 V). The fourth presents reflections and comparisons between the Industrial Revolution in England and the energy transition in Ceará, offering a critical analysis of how the latter could benefit from the planning strategies of the former.

The Importance of History for Understanding the Present

The historical context provides insights that enable the understanding of the origins of events that shaped an era, enhancing present decision-making by drawing on lessons from the past. The Renaissance thinker Niccolò Machiavelli inferred that historical events could assist political, economic, and social agents in making better decisions in the present.

In The Prince (1513), Machiavelli (2023) highlights that men often traverse paths already explored by others. While it is impossible to follow those paths precisely or fully attain the virtues of those being imitated, a prudent individual should strive to emulate the most excellent figures to derive at least some benefit.

In Philosophy of History, Pecoraro (2021) explains that a cyclical view privileges both past and present in interpreting or predicting the fate of states, based on a conception of time and history that alternates and repeats indefinitely. Similarly, the German historian Reinhart Koselleck (1923–2006) asserts that history grants us the freedom to replicate past successes rather than repeating old mistakes in the present.

According to Pereira and Gomes (2022, p. 04): "Understanding history, especially that of one's own context, is closely linked to individual formation, the development of social and personal identity, critical thinking, and the ability to position oneself as an agent of historical change".

This leads to the following question: Is it possible to construct a critical analysis based on the historical context of the First Industrial Revolution and consider it in the current landscape of the energy transition underway in Ceará?

The First Industrial Revolution in England (1760–1850)

England is an island country located in the North Atlantic and the western part of Europe. From the 17th century onward, various circumstances led to profound transformations in English society in the following century. According to Lima and Oliveira Neto (2017), successive inventions gave rise to English factory production due to improvements in the manufacturing process. Driven by political, economic, social, and scientific-technological factors, among others, the First Industrial Revolution became a landmark in human history, reshaping the course of the global economy and abolishing the feudal system (Iglésias, 1990). It was a unique phenomenon, as England's industrial development was driven by early technological progress without interference from previously industrialized nations (Arruda, 1988).

Political Aspects

In 1651, the English Parliament, under Oliver Cromwell, enacted the Navigation Acts (Passionate about History, 2020). These measures enabled England to control key maritime trade routes, as they mandated that no goods could be imported or exported except via English ships (Domingues, 2024).

In 1688, the Glorious Revolution abolished Absolutist Monarchy, replacing it with a Constitutional Parliamentary Monarchy. This shift in governance led to political stability and strengthened the economic class, as many of its members also held parliamentary positions. Additionally, alliances between the monarchy and economic elites were consolidated, contributing to commercial expansion, capital accumulation, and the advancement of capitalism (Lima, & Oliveira Neto, 2017; Iannone, 1992; Mello, 2012).

These circumstances enabled investments in economic infrastructure, such as the construction of ports and railways, the strengthening of the naval industry, and the expansion of the merchant fleet. Moreover, an increasing number of parliamentary laws and acts were enacted to support manufacturing activities (Iannone, 1992).

From a geopolitical perspective, England's strategic and privileged location in the North Atlantic allowed it to quickly access the main maritime trade routes of the time, including the Atlantic and Indian Oceans. It can be partially concluded that, in terms of political influence, the alliances between the monarchy and economic powers, the country's political stability, and the accumulation of capital by the monarchy were essential factors for the emergence of the First Industrial Revolution.

Economic Expression

The British economy underwent a series of structural transformations that positioned it as the "first industrialized country"[11]. According to economist David Landes, a renowned Professor at Harvard University, the English Industrial Revolution is understood as the first historical example of the transition from an agrarian and artisanal economy to one dominated by industry and mechanized manufacturing (Landes, 2005).

Historically, this transformation was driven by a series of economic opportunities that were meticulously exploited. According to Lima and Oliveira Neto (2017, p. 103), "the world witnessed a broad and profound transformation in English society, where production shifted from agrarian and artisanal to an industrial economy based on capitalist methods, principles, and practices."

This transition was propelled by factors such as the abundance of raw materials from agriculture, which played a central role in the industrialization process. Wool and cotton production, for instance, not only sustained the agrarian economic base but also enabled the advancement of the textile industry, creating favorable conditions for technological development and economic growth. "In agriculture, the country was a major producer of wool and cotton, which allowed it to transform the industry and drive economic development. These products were used in the textile industry, fostering progress in spinning and weaving manufacturing (Mello, 2012)".

No other country had such an abundant supply of wool, particularly long-fiber varieties required for lighter and more durable fabrics, as highlighted by Landes (apud Lima, & Oliveira Neto, 2017, p. 110). In the 18th century, various inventions revolutionized the cotton industry, giving rise to a new production model known as the factory system (Landes apud Lima, & Oliveira Neto, 2017). Later, in the 19th century, the expansion of manufacturing transformed the country into the world's largest industrial hub, pioneering many innovations. As a result, English industrial processes experienced significant advancement (Iannone, 1992).

The availability of coal and iron reserves was crucial for energy production and the construction of machinery and equipment, respectively[10]. Moreover, advancements in the steam engine secured a new energy source, surpassing water, animal, and human power, thereby consolidating textile production and metallurgical activities (Iglésias, 1990).

To facilitate the domestic market distribution of products, investments were made in transportation infrastructure, including roads, bridges, and canals. Additionally, production centers gained access to navigable waterways, reducing distribution costs (Mello, 2012).

For overseas trade, the country invested in ports, ensuring better conditions for imports and exports (Lima & Oliveira Neto, 2017), thus strengthening international trade and the British naval industry (Iannone, 1992). It is noteworthy that the British Empire benefited from the "colonial pact" (where the metropolis engaged in trade with other countries, while the colony was restricted to trading only with the metropolis) within the context of the commercial revolution.

Consequently, Britain faced no restrictions on accessing raw materials to supply its industrial sector (imports) and had a guaranteed consumer market for its exports—initially in Europe, later expanding to the Americas, Asia, and Africa. Thus, foreign trade played a vital role in driving British economic growth. Indeed, export-oriented industries experienced rapid growth, with a 4.6% annual increase between 1780 and 1800, making this sector the primary contributor to the significant expansion of the British economy (Arruda, 1988). The transition from artisanal production to mass production resulted in increased productivity (Iannone, 1992). This shift replaced human skills with mechanical devices and human labor with energy sources (Mello, 2012).

Mass production enabled economies of scale, reducing the costs of industrialized goods and enhancing competitiveness in international trade. Furthermore, this process cemented British commercial supremacy, elevating the nation to global power status through the implementation of a liberal economy. This success was justified by the judicious use of production factors, including raw materials, labor, energy, transportation, consumer markets, capital investment, and technology.

However, the First Industrial Revolution also brought negative consequences. Economic transformations were accompanied by environmental degradation, including increased air pollution, water contamination, and soil depletion. In other words, industrial development was not sustainable, as it relied heavily on non-renewable and polluting energy sources, particularly coal.

As a partial conclusion, it can be inferred that the availability of natural and mineral resources, investments in transportation infrastructure, the strengthening of international trade, and technological innovations played a fundamental role in the First Industrial Revolution. However, a significant negative legacy was the severe air pollution and extensive environmental degradation that resulted from industrialization.

Social Expression

Between 1600 and 1700, the population of London doubled compared to the period from 1500 to 1600, reaching approximately one million inhabitants by 1800. In the 18th century, the level of urbanization increased throughout England as a result of the export of manufactured goods to the colonial market (Mello, 2012).

Part of the workforce employed in the textile, steel, and metallurgical industries came from the countryside, as since the 16th century, the nobility had been expelling peasants from their lands (a process known as enclosure) to convert them into sheep pastures, whose wool was widely traded in the production of textiles (Iannone, 1992).

As a result, many farmers were forced to seek new occupations, leading to large-scale migration to the cities. Consequently, the growing process of urbanization was considered crucial for changes in consumption patterns of the time, tied to the advancement of commercialization and industrialization. Several key factors contributed to the development of the country's internal market: population growth, improvements in communication, rising average incomes, and commercial free enterprise (Lima, & Oliveira Neto, 2017).

According to Landes (Mello, 2012), English income was high by international standards, meaning that the country had well-paid workers; wages were high, allowing for significant purchasing power. Allen (Mello, 2012) noted that, in terms of consumption, well-paid workers spent more on manufactured goods, thus creating a large domestic market for consumer goods such as textiles. Furthermore, the technical capacity of English craftsmen was another distinguishing factor: a mill builder was a skilled mathematician and knew something of geometry.

In 18th-century England, there was an unparalleled level of technical qualification compared to the continent, where the English people were much more interested in machines and "gadgets" than in other European countries (Mello, 2012). Thus, the English social system underwent rapid transformations due to changes in the production system and labor relations (Arruda, 1988). It can therefore be inferred that the intense urbanization process in the country, the availability of labor in factories, the technical qualification of the English people, and the wage levels (average income) of the population fostered the production and consumption of goods in England, thereby contributing to the First Industrial Revolution.

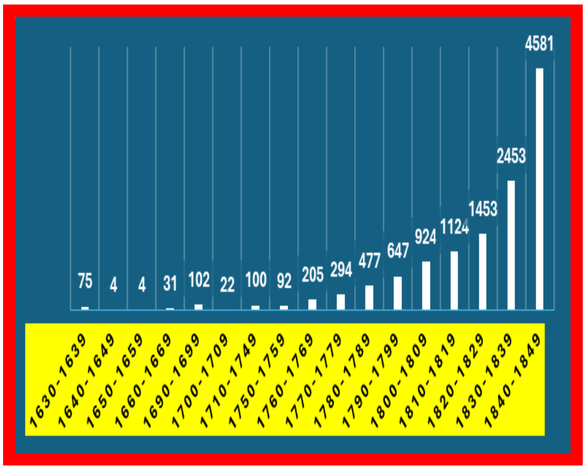
Scientific-Technological Expression

The political, social, and economic success that occurred in England was also reflected in the scientific-technological expression. According to Landes (apud Lima & Oliveira Neto, 2017), technological change was made possible by the improvement of new methods that addressed the inadequacies of the existing techniques, creating a new entrepreneurial mindset when analyzing investments and potential risks.

As a result, it became possible to produce goods that would have been impossible to manufacture using the old artisanal methods. The impetus given to innovation was crucial for seeking more efficient methods that created a conducive environment for inventions (Lima & Oliveira Neto, 2017). Its development was likely a consequence of the growing commercial competition, which provided strong incentives for improving production methods. These innovations became more pronounced from the second half of the 18th century, facilitated by the development of mechanical energy (Iannone, 1992).

Mello (2012) argues that the Industrial Revolution was fundamentally different due to the cumulative advancement of technology, making economic growth irreversible. The steel and metallurgy sectors experienced technological progress at the end of the 18th century, although these transformations were less radical than those that occurred in the textile sector (Iannone, 1992). To better understand the innovations in the scientific-technological field, one of the chosen indicators was the number of patents registered in England from 1630 to 1849.

Graph 1: Patents registered in England from 1630 to 1849



Source: Iglésias (1990, p. 67). Adapted by the Author.

As observed in Graph 1, prior to 1760 (the beginning of the First English Industrial Revolution), the number of patented inventions was very low. From 1630 to 1759, only 430 inventions were registered, while from 1760 to 1849, the number skyrocketed to 12,158. These figures attest to the remarkable and unbelievable leap in inventions in England, highlighting how research, development, and innovation played key roles in the country's advancement.

According to the data in Graph 1, Mello (2012) clarifies that the country had skilled professionals to introduce innovations and entrepreneurs to develop them, foreseeing a much better investment opportunity than traditional methods (Mello, 2012). These inventions resulted in the rapid advancement of three key sectors in the English economy: iron foundry, cotton spinning, and steam power production (Arruda, 1988).

The results also signified intellectual autonomy, the consolidation of the scientific method, and the development of research as a routine activity in England (Lima & Oliveira Neto, 2017). In light of the above, it can be inferred that the creation of new production methods and techniques, the intensification of research and development in the country, leading to the emergence of numerous innovations and products under the responsibility of highly skilled individuals, enabled England to become a global power in the field of Science and Technology. As a final summary of the factors that contributed to the First Industrial Revolution, a brief outline of these factors is presented in Table 1.

Table 1: Success Factors in the First Industrial Revolution

Aspect	Factors for Success in the 1st Industrial Revolution
Political Aspect	- Alliances between royalty and economic powers
	- Political stability in the country
	- Capital accumulation
Economic Aspect	- Availability of natural and mineral resources
	- Investments in transport infrastructure
	- Strengthening of international trade
	- Technological innovations
Social Aspect	- Urbanization of the country
	- Availability of labor
	- Technical qualification
	- Wage levels (average income)
Scientific-Technological Aspect	- Creation of new production methods and techniques
	- Intensification of research, development, and innovation
	- Human resources with high technical qualifications

Source: Data from the researchers.

Based on Table 1, it is possible to assess the feasibility of leveraging the lessons from England to reflect upon and derive new perspectives or insights for the energy transition in the State. With a forward-looking perspective, one can anticipate the applicability of the lessons learned during the 1st Industrial Revolution to the current context of Ceará.

These lessons can be utilized to adopt new technologies, foster innovation in production processes, and implement strategies to drive sustainable development and local industrialization, considering the growing demand for renewable energy sources and more efficient practices in the use of natural resources.

By observing England's success in this historical process, Ceará could integrate practices such as technical qualification, research and development promotion, in addition to investing in strategic sectors such as solar energy and biofuel production.

Energy Transition in Ceará with H_2V in the 21st Century

The subtopic Energy Transition in Ceará with H_2 V in the 21st Century will be analyzed through four key dimensions: political, economic, social, and scientific-technological. To structure this discussion, it will be divided into the following sections: 3.3.1 Political Expression, which examines governmental policies and regulatory frameworks; 3.3.2 Economic Expression, focusing on investments, market dynamics, and economic impacts; 3.3.3 Social Expression, addressing societal implications and workforce transformations; and 3.3.4 Scientific-Technological Expression, exploring research advancements and technological innovations driving the green hydrogen sector in Ceará.

Political Expression

The State is located in the northeastern region of Brazil, bordered by the South Atlantic Ocean (which holds significant economic relevance in the globalized world), contributing to commercial exchanges with the international community (Barbosa, & Gomes, 2024).

Regarding the energy transition, this study considers the establishment of the Hydrogen Hub at the Port of Pecém as the main political milestone, with the State Government playing a key role in political articulation (at both the state and federal levels) through the provision of tax incentives, access to basic education, and technological training. Additionally, the Government has made institutional efforts to facilitate environmental licensing and provide the necessary infrastructure for the execution of H2V projects (UFC, 2021).

On the international front, it has been engaging in paradiplomacy with foreign governments and institutions. The creation of the hub was launched 14 years ahead of the Triennial Work Plan of the Ministry of Mines and Energy, in 2021, alongside the Federation of Industries of the State of Ceará (FIEC) and the Federal University of Ceará, within the Pecém Industrial and Port Complex (Bezerra, 2023).

This initiative coincided with a global trend suggesting that the potential for renewable energy generation and the strategic location of ports would stimulate the creation of hydrogen hubs, contributing to the development of the market, technology for the national industry, and providing a platform for access to other countries (Oliveira, 2022).

Two years later, in May 2023, Ceará established a maritime corridor with the Government of the Netherlands, creating a route for the future commercialization of H_2V to Europe (Vasileva, 2023). The bilateral agreement involved the ports of Pecém and Rotterdam (the largest maritime port in Europe). This strategic alliance in international business was made possible through a joint venture, with Rotterdam holding 30% of the control of the Pecém Complex. In September 2024, the State Government and FIEC launched the Green Hydrogen Masterplan (FIEC Online, 2024).

This publication presents the studies conducted by the American consultancy IXL Center, with participation from Harvard University, the Massachusetts Institute of Technology, senior researchers, consultants, and representatives from various local public and private organizations. In October 2024, the Government signed a pre-contract worth R$ 9 billion with the Norwegian company Fuella AS (developer and operator of H_2V and ammonia plants) to establish a plant in the Export Processing Zone of the Port of Pecém (Pecém Complex, 2025), anticipating the creation of over one thousand jobs.

In January 2025, reaffirming its political efforts to consolidate H_2V, the Governor of Ceará met with the CEO of the Port of Rotterdam (Pecém Complex, 2025) to establish new partnerships and strengthen projects between the two ports. It is also worth noting the resurgence of the Pacto pelo Pecém in August 2023 (FIEC Online, 2023).

The program brings together political sectors (State Government, Legislative Assembly, and municipal governments), industrial sectors (FIEC and the Association of Companies in the Pecém Industrial and Port Complex), academic sectors, civil society, and environmental groups. Its purpose is to foster multilateral governance with social and environmental sustainability. One of the key components of the Pacto pelo Pecém is the Hydrogen Hub as a center for clean energy production. In the context of the energy transition in Ceará, the interinstitutional integration presented in the State aligns with the International Energy Agency's report, which asserts that the development of low-carbon hydrogen production is a challenge that will require simultaneous work on multiple fronts, coordinated across all stakeholders, including governments, industry, research and innovation agencies, financial services, trade unions, and civil society (IEA, 2022).

In these circumstances, the State of Ceará emerges as a potential provider of H_2V to the international market, thanks to the Hydrogen Hub at the CIPP. The complex has attracted significant public and private investments and has hosted major energy projects. Thus, the State has continuously strengthened alliances and partnerships with economic, industrial, and academic institutions within the Triple Helix framework.

Economic Expression

Ceará's prominence in the production of Green Hydrogen (H_2V) has the potential to open opportunities for the development of an export market and strengthen international partnerships based on converging interests. The consolidation of the production chain would contribute to the decarbonization of industry, transportation, and the development of the ecosystem within the state, ensuring greater energy security.

Its geographic position (low latitude and proximity to the Equator) enables it to economically exploit solar energy, generating a photovoltaic potential of 643 GW (Cavalcante, 2023). In the wind context, various studies indicate favorable conditions for the installation of wind farms by applying the Weibull probability distribution (Silva et al., 2020).

Being located within the solar belt and benefiting from wind conditions, Ceará also enjoys a promising solar photovoltaic and wind potential due to what is referred to as energy complementarity. Thus, Ceará's H_2V production would bring operational, logistical, and commercial advantages that are more attractive and competitive, positioning the state as a renewable energy provider to Europe, surpassing other producer countries. "It is noteworthy that Europe is more focused on using H^2V to decarbonize the industrial and heavy transport sectors (buses and trucks), and it is expected to remain the largest market in the short term (Oliveira, 2022)".

The Pecém port, by facilitating numerous trade routes, emerges as a key logistical infrastructure, representing a turning point in the state's economic development (Alberto, 2024). By serving as a vital link in global supply chains, it is expected to enable the integration of port and industrial activities (industrial port), including in the H_2V value chain. In terms of investments, "The World Bank and the Ministry of Development, Industry, and Foreign Trade (MDIC) funded the hydrogen hub infrastructure with 100 million dollars (Vasileva, 2023)".

Furthermore, the State Government has made investments through the Secretariat for Economic Development and the Secretariat for Infrastructure. These activities aim to enhance the use of the complex as an economic development strategy, while also ensuring appropriate and diversified logistical infrastructure.

Based on a multi-stakeholder cooperation model, one of the major successes of the hub was the ability to bring together various national (public and private) institutions and multinational companies in a single port complex, allowing the construction of a "coastal industrial cluster" with good management and governance, providing long-term stability (Raccichini, Contardi, & Ristuccia, 2022).

Among these dynamics, the importance of integrating different spheres of the economy and management stands out, creating a collaborative network that maximizes available resources and strengthens the competitiveness of the hub. Efficient coordination between the involved parties allows not only the optimization of infrastructures but also the creation of synergies that favor innovation and the sustainable development of the complex. These characteristics, applied to the Suez Canal context, demonstrate how combining strategic models can lead to substantial gains in efficiency and operational cost reductions. “This architecture (port, export, industrial, and energy) found in the Suez Canal Economic Zone (Egypt) would contribute to cost reduction by having shared infrastructures (IEA, 2022)”.

Another significant aspect was the implementation by FIEC, in 2022, of the ESG Program (Environmental, Social, and Corporate Governance) (FIEC, 2024c), unprecedented in the Brazilian industrial system and one of the most discussed topics in the corporate world. This initiative aims to guide Ceará’s industries in sustainability projects, incorporate best environmental preservation practices into production processes, and reduce the operational impacts. With the ESG Hub, environmental management was incorporated as an incentive for companies to conduct their activities in an environmentally safe manner, promoting the development of products that have no environmental impact and provide better performance in terms of energy efficiency and natural resource use.

As highlighted by Bezerra (2023), in the industrial sector, the manufacture of "green products" without greenhouse gas (GHG) emissions would constitute a highly promising market in the coming years, due to the expectation of product taxation in various countries that generate GHGs in their production process.

Additionally, companies are increasingly adopting social and environmental responsibility initiatives to improve their image with consumers. This is the scenario in which Ceará finds itself, full of market opportunities that could make it a participant in the global energy transition as well as alter the socio-economic profile of the state derived from the production and export of H_2V, an energy vector from renewable and non-polluting sources. However, there are some challenges to be overcome in the process of H_2V production in Ceará that could hinder or delay the energy transition, compromising the state’s competitiveness on a global scale. The first challenge is water. “The separation of hydrogen and oxygen from the water molecule occurs through a direct current flow across electrodes (cathode and anode) immersed in an alkaline aqueous solution at ambient temperature (Castro et al., 2023)”.

Consequently, H_2V production requires a significant amount of water. According to a report from the International Renewable Energy Agency (IRENA), "H_2V will be most economically produced in locations that combine abundant renewable resources, available land, access to water, and the capacity to transport to large importing countries (IRENA, 2022)".

However, regions with the greatest potential for renewable energy and space for H_2V plants are increasingly experiencing water stress. Ceará is one such region with water scarcity. To ensure water stability, the state would need to seek alternatives for recycling or desalinating water (FIEC, 2024a).

“The second challenge is labor costs, which are considered intermediate (lower than developed countries but higher than those in India), but the disadvantage relative to some countries is not enough to eliminate the state's advantageous position (FIEC, 2024a)”.

“The third challenge is Brazilian taxation, considered the only component of the structured cost that could harm Ceará’s (and Brazil’s) competitiveness. Therefore, it is important for this issue to be addressed by both federal and state governments (FIEC, 2024a)”.

The fourth challenge is infrastructure. Among the 17 Sustainable Development Goals proposed by the United Nations, Goal 9, titled "Industry, Innovation, and Infrastructure," aims to "build resilient infrastructures, promote inclusive and sustainable industrialization, and foster innovation." Investments in infrastructure and innovation are essential for economic growth. In the 2024 FIEC Innovation Index, the state of Ceará ranks 19th out of 27 states in Brazil, and 6th in the Northeast (FIEC, 2024b).

Therefore, it is essential to develop infrastructure capable of supporting the economic demands aimed at the development of H_2V in the state.

Social Expression

In the 2023 Basic Education Development Index (IDEB), Ceará achieved the best result in Brazil for Elementary Education, considering only the public-school network. In the state network, it recorded the third-best score in Brazil for both Traditional High School and High School integrated with Professional Education (Falcão, 2024).

These performances are a clear indicator of the educational level of Ceará's youth. In the context of the energy transition, the State of Ceará has also made significant strides in human resources training. A noteworthy example occurred in May 2024, when the State Project H-TEC for Qualification and Strengthening the Renewable Energy Production Chain was launched (FIEC Online, 2024).

The H-TEC project aims to support the training of qualified professionals, in partnership with the State Government of Ceará, the Cearense Foundation for Support to Scientific and Technological Development, the National Service for Industrial Apprenticeship (SENAI/FIEC), the Federal University of Ceará, the State University of Ceará, and the Federal Institute of Education, Science, and Technology of Ceará. The course load is 360 hours, with SENAI responsible for delivering practical lessons covering topics such as hydrogen, energy distribution, wind energy, solar energy, and occupational safety. It is estimated that 1,050 professionals will be trained in the first phase, with an expectation of 10,650 professionals by 2026 (FIEC Online, 2024).

Additionally, there is a collection of SENAI courses focused on human resource training in renewable energy, which can be seen in Table 2, outlining the training programs offered by the institution.

Table 2 - Trainings conducted by SENAI.

Course/Training/Workshop	Workload
Technology in Wind Energy Wind	32 hours/class
Turbine Blade Repair Technician	160 hours/class
Hydrogen, Energy (Wind and Solar), and Occupational Safety	360 hours/class
Assembly of Photovoltaic Systems	40 hours/class
Commissioning of Photovoltaic Systems	40 hours/class
Assembly of Photovoltaic Systems	40 hours/class
Safety Applied to Hydrogen Storage and Distribution	60 hours/class

Source: Researchers' data

The information in Table 2 demonstrates the commitment of the industrial sector to ensure the necessary qualifications in the technological-energy field. In turn, the Federal University of Ceará stands out in technical-scientific training in the field of energy transition. Its involvement includes providing faculty and researchers in areas related to H^2V technology, making laboratories available for research and teaching, and proactively participating in ongoing research (UFC, 2021).

To this end, it has, in its academic infrastructure, the Technological Park to stimulate the production of knowledge. The Federal Institute of Education, Science, and Technology is also focusing on training human resources for renewable energy.

The Institute has a campus within the CIPP area. In 2024, it launched a specialization course (postgraduate level, lato sensu) with the support of the German Cooperation Agency (GIZ), aimed at developing solutions in the production, distribution, and applications of H_2V (IFCE, 2024).

Finally, the Euvaldo Lodi Institute (IEL) has been accumulating expertise to train professionals in the energy sector, meeting current market demands. Examples include the MBA in Renewable Energy Management (392 hours), in partnership with Farias Brito University Center (FIEC Online, 2023), and the Renewable Energy and Green Hydrogen Management Course (64 hours).

The students of the aforementioned MBA program produced more than 30 scientific articles within the theme of renewable energy. Among these articles, the majority were published in international journals, reflecting the scientific quality of the course.

Scientific-Technological Expression

An important milestone in the context of H_2V was the launch, in March 2024, of the Renewable Energy Research and Innovation Network (Rede VERDES) (FIEC Online, 2023): an initiative aimed at conducting basic and applied research in a collaborative and multidisciplinary manner, focused on various types of clean energy. IEL/FIEC, as a Scientific and Technological Institution (ICT), coordinates this strategic network, which strengthens the relationship between academia and the productive sector. At its inception, the Network consisted of more than 100 researchers from 26 Research Units of 14 Higher Education Institutions and ICTs. It is noteworthy that the VERDES Network facilitates the transfer of technology to the energy sector, generating socio-economic and environmental impacts[18].

The Jurandir Picanço Center of Excellence in Energy Transition, considered the first of its kind within the National Confederation of Industry, is another example of the priority given to innovation by Ceará, reaffirming FIEC's commitment to decarbonization efforts. The inauguration of the infrastructure[18] took place in March 2024, contributing to the training and development of the workforce dedicated to the production of clean energy in the State (FIEC Online, 2024).

In 2024, the "FIEC Innovation Index of States" was released. This index enables the design and implementation of public policies aimed at fostering an innovative ecosystem, with the participation of entrepreneurs, universities, public entities, and the third sector (FIEC, 2024b).

In the overall result, for the second consecutive year, Ceará was the most innovative state in the Northeast region, achieving 8th place in the national ranking (FIEC Online, 2024). From the analysis of Table 3, it is possible to infer a base of essential information for defining state strategies and policies capable of transforming the innovation ecosystem, leading the industry to a new level of productivity and competitiveness (Souza Filho, 2019).

Table 3: Relative Position of Ceará in the FIEC Innovation Index

Indicator	Brazil	Northeast
Human Capital (Undergraduate)	11th	3rd
Human Capital (Postgraduate)	9 th	2nd
Masters and PhDs	11 th	2nd
Public Investment and Funding in S&T&I	9 th	1st
Infrastructure	**19 th**	**6 th**
Institutions	11 th	2nd
Global Competitiveness	**8 th**	**1st**
Entrepreneurship	**27 th**	**9 th**
Scientific Production	13 th	5 th
Technological Intensity and Creativity	4 th	1st
Intellectual Property	13 th	4 th
Environmental Sustainability	5 th	2nd
Overall Position of the State of Ceará	**8th**	**1st**

Source: FIEC Innovation Index of States 2024 (FIEC, 2024b)

In the context of the energy transition, the FIEC Innovation Index serves as a crucial analytical and decision-making tool that facilitates the understanding of scenarios in Ceará and can certainly contribute to the state's energy transition process. From the data presented in Table 3, the most significant negative scenario was the extremely low level of entrepreneurship at the national level.

Considered central to the dissemination of innovation, entrepreneurship promotes the creation and consolidation of businesses that drive a dynamic business environment. "In the 2024 Index, the state of Ceará ranks last nationally. In such circumstances, measures must be taken to reverse this situation (FIEC, 2024b)".

3.4 Reflections between the Industrial Revolution and the Energy Transition

Analyzing the two events studied (distant in both time and space), while the First Industrial Revolution involved a strong integration of energy and technological resources, significantly boosting the English industrial sector; in the Energy Transition in Ceará, we observe an intense integration of the industrial complex with technology, resulting in the production of H_2V.

Thus, throughout the research, there are similarities as well as differences. For the criteria that were similar, it is reasonable to conclude that the State would have a great benchmark in maintaining the current plans, allowing it to refer to past successes. On the other hand, for the criteria that differ, it would be possible to critically reflect on each situation, either ratifying or adjusting strategic actions that could maintain or improve the process of implementing and consolidating H_2V. In this dynamic, historical references from the first event could, eventually, guide decision-making in the present, aligning with the assertions of Machiavelli, Peccorato, and Koselleck.

Thus, Table 4 below provides insights that allow for a critical analysis. In the Political Expression, both events have similarities, particularly the concept of the Triple Helix in the State, which has been a differentiating factor in the implementation of H_2V in Ceará.

In the Economic Expression, the energy transition in Ceará is associated with the use of renewable, non-polluting energies with low environmental impact, conditions much more favorable than those observed in the 18th century. However, a major challenge throughout this process is finding alternatives for water stress in the State of Ceará. Monitoring investments in economic infrastructure, especially in the transport system, improving entrepreneurship in Ceará's society, and paying attention to issues related to taxes, taxation, and labor costs are conditions that deserve attention.

In the Social Expression, both events have similarities as public and private managers have driven the training of human resources to provide education to youth and offer appropriate technical qualification and specialization to the workforce designated to perform functions in the complex environment that composes the industrial and energy system.

Table 4: The 1st Industarial Revolution and the Energy Transition Process in Ceará.

Comparative Criteria		Industrial Revolution	Energy Transition
Political Expressio n	Position (Location)	Optimal (North Atlantic)	Very good (South Atlantic)
	Maritimity	Access to important maritime trade routes	Idem

	Political Integration	Strong alliance between Nobility and Economic Power	Strong integration of Government, Industry, and Academia (Triple Helix)
Economic Expression	Raw Material	Iron ore, coal, wool, and cotton	Rich sources of renewable energy (sun and wind)
	Energy	Non-renewable and polluting	Renewable and non-polluting
	Transport (domestic market and international trade)	Road, rail, and maritime	Idem
	Overseas consumer market	Europe	Idem
	Capital Investment	Infrastructure in transportation, industry, and energy	Need for investments in economic infrastructure
	Competitive Advantages	Task division, production line, productivity, economies of scale, and cost reduction	Renewable energy, H_2V Hub
	Entrepreneurship	High	Low
	Environmental Impact	High	Low
	Taxes and Taxation	Not addressed in the article	Requires attention
	Labor Costs	Not addressed in the article	Requires attention
Expression ; Social	Human Resources	Specialized	High Specialization (H-TEC Qualification)
Scientific-Technological Expression	Technology;	Intensive research and development; High numbers in innovations and patent registrations (inventions);	Triple Helix (State Government, UFC, IFCE, IEL, and SENAI); VERDES Network and Jurandir Picanço Center of Excellence in Energy Transition.

Source: Researcher Data

In the Scientific-Technological Expression, both events have similarities considering that the institutions that make up the Triple Helix are focused on research and development. The highlight is the conducting of training through the VERDES Network and the Jurandir Picanço Center of Excellence in Energy Transition.

IV. Conclusion

History helps to develop critical thinking by understanding what happened in the past, subsequently contributing to the ability to gain new perspectives in the present moment. In this regard, the First Industrial Revolution served as the historical reference to project its main events, which took place in the 18th century, onto the ongoing energy transition in Ceará. In the political, economic, social, and scientific-technological fields, it was possible to identify criteria that both resembled and differed in the complex scenario of the development of the H_2V production chain in the state.

Thus, the primary objective of this article was to reflect on and compare the First Industrial Revolution with the energy transition in Ceará. As a result of these reflections, it describes how the former could offer insights and critically contribute to the ongoing energy transition process.

The research achieved its objectives by providing insights from the 18th century into the current scenarios in Ceará, including aspects that could be improved in the current circumstances in order to consolidate the energy transition. The qualitative approach (literature review) was essential for understanding the historical dynamics in England and the realities experienced in Ceará, allowing for the construction of a critical perspective of the latter based on the former. Although these events are separated by time and space, and in the specific contexts of each historical moment, the research revealed that the First Industrial Revolution provides understandings that can potentially enhance critical analysis and decision-making by political, economic, and academic leaders in favor of consolidating the energy transition in Ceará.

Therefore, it is confirmed that history proves to be a great ally in interpreting the past, facilitating the understanding of the present, and contributing to defining a future perspective.

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