IOSR Journal of Business and Management (IOSR-JBM)
e-ISSN:2278-487X, p-ISSN: 2319-7668. Volume 26, Issue 12. Ser. 12 (December. 2024), PP 66-70
www.iosrjournals.org

Green Hydrogen And Education: Ceará's Role In The Brazilian Energy Transition

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Abstract:
Background: *The Brazilian Basic Education system, particularly in the state of Ceará, is pivotal in preparing students to face the challenges and opportunities of a low-carbon economy, especially with the integration of green hydrogen production. By incorporating study subjects focused on sustainability, renewable energy, and technological innovation into the school curriculum, Basic Education promotes the development of critical and scientific thinking from an early age. This knowledge is essential for professional training, enabling the implementation of clean technologies, such as green hydrogen production, using Ceará's abundant wind and solar energy resources.*
Materials and Methods: *The research adopted a qualitative approach, utilizing two methodological procedures: (1) bibliographic research for theoretical grounding and analysis of essential concepts, and (2) documentary research focusing on institutional and regulatory sources supporting discussions on Ceará's initiatives within the energy transition context.*
Results: *The study identified that initiatives like H-TEC and educational practices in Natural Sciences and Mathematics significantly contribute to Ceará's role in the Brazilian energy transition. These initiatives emphasize the importance of fostering knowledge and technology areas to enhance education and prepare students for active roles in the renewable energy sector.*
Conclusion: *Strengthening education in sustainability, renewable energy, and technological innovation equips students to contribute to the global energy transition. This effort supports the development of an economically sustainable, greener, and more prosperous future, aligning with the goals of the Brazilian energy transition.*
Keywords: *Education; Challenges; Green Hydrogen; Economy; Low Carbon.*

Date of Submission: 10-12-2024 Date of Acceptance: 20-12-2024

I. Introduction

The climate crisis represents one of the greatest challenges faced by humanity, characterized by rising global temperatures, extreme weather events, and ecosystem degradation. Its causes were already highlighted in the early 1990s through the Intergovernmental Panel on Climate Change (IPCC, 1990) report, considered a milestone in addressing the challenges posed by climate change. In response, societies worldwide are adopting sustainable energy solutions to reduce greenhouse gas emissions and transition to a low-carbon economy. Among the most promising solutions is green hydrogen (H_2V), a clean energy carrier produced from renewable resources such as wind, solar, and biomass.

According to the International Energy Agency (IEA), hydrogen is experiencing an unprecedented political and commercial momentum, with a rapidly expanding array of policies and projects worldwide (IEA, 2023). The integration of H_2V into educational curricula aligns with global energy transition priorities, fostering sustainability and innovation.

The Northeastern region of Brazil, particularly the state of Ceará, has significant potential in renewable energy, positioning itself as a future hub for H_2V production. However, this transition requires a qualified workforce with solid training in Natural Sciences and Mathematics, highlighting the importance of high-quality education in these areas. Despite educational reforms in Ceará that have improved student performance in these disciplines, there remains a critical gap in including study topics related to H_2V in Basic Education curricula.

The current educational system lacks programs or activities designed to inspire and prepare students for careers in this context. Bridging this gap is essential, considering H2V's strategic role in the global energy transition and Ceará's potential leadership in this field. The approach adopted for this research was qualitative, employing two methodological procedures: bibliographic research for theoretical grounding and analysis of essential concepts, and documentary research focusing on institutional and regulatory sources supporting discussions about Ceará's initiatives in the energy transition context.

The general aim of this study is to investigate how Ceará, through initiatives like H-TEC and educational practices in the teaching of Natural Sciences and Mathematics, contributes to the Brazilian energy transition, focusing on green hydrogen development and professional training for the renewable energy sector. To achieve this aim, the following specific objectives were defined: (i) analyze technological and scientific advancements related to green hydrogen in the global and national context, highlighting Ceará's strategic role; (ii) identify and discuss educational practices and methodologies employed in the teaching of Natural Sciences and Mathematics in Brazil, with emphasis on Ceará, assessing their relationship with professional training for renewable energy sectors and green hydrogen development; and (iii) examine the structure, objectives, and impacts of the H-TEC Plan on workforce qualification, evaluating its contribution to strengthening the renewable energy production chain and Ceará's leadership in the Brazilian energy transition.

The study investigated gaps in curriculum integration, student preparation for technical courses, educational policies, evaluation systems, and incentive programs at federal and state levels. Furthermore, it suggests the development of specialized educational materials and the implementation of incentive programs such as events and competitions to engage students and promote sustainability-focused education (UNESCO, 2017).

This article is structured into four sections: following the introduction, which contextualizes the challenges posed by the climate crisis, the second section presents the relevance of Basic Education in a low-carbon economy. The third section outlines the methodology, and the fourth concludes with considerations about the role of Basic Education in developing a low-carbon economy through Green Hydrogen (H2V).

II. Material And Methods

The approach adopted for the development of this study is qualitative, a choice based on the ability of this methodology to provide an in-depth understanding of the phenomena under analysis and to allow for an interpretative analysis of the collected data. Qualitative research is widely recognized in the scientific community for its flexibility and analytical richness, enabling a detailed examination of contexts, practices, and processes. It facilitates a more holistic and subjective investigation, essential for understanding complex topics such as the energy transition and the integration of green hydrogen into Ceará's educational and socioeconomic context. This approach provides a closer look at the nuances of the studied phenomena, supporting the development of theories and practices applicable to specific contexts (Gonzalez, 2020).

To conduct this research, two methodological procedures were employed: bibliographic research and documentary research. Both are essential for building solid and reliable knowledge and were chosen for their relevance in addressing the proposed topic. The bibliographic research was carried out through a review of the principal scientific works published between 2013 and 2024, including academic articles, books, theses, and dissertations addressing green hydrogen, the energy transition, and the teaching of Natural Sciences and Mathematics.

This procedure was crucial for providing a theoretical foundation for the analysis, enabling the consultation of updated and relevant sources discussing scientific and technological advances in renewable energy, education, and Ceará's role in this process. Bibliographic research stands out for its ability to provide a robust knowledge base, allowing researchers to understand the current state of research on the subject and identify future directions for exploration. Documentary research, in turn, focused on the analysis of regional and international documents addressing energy transition, emphasizing green hydrogen and the educational and energy policies applied in Ceará (Carvalho, 2020).

Reports, strategic plans, and public policies were analyzed at both national and international levels, including documents from the Ceará government and international organizations such as the International Energy Agency (IEA) and the European Union. Documentary research is a critical procedure as it enables access to official, historical, and strategic records, providing an in-depth understanding of public policies and their implications. This type of research also involves the analysis of primary sources, offering greater authenticity and relevance to the collected information (Guerra, 2023).

These two methodological procedures—bibliographic research and documentary research—were combined to provide a comprehensive and well-founded understanding of the central themes of this study. This combination allowed for establishing a connection between scientific advancements, educational practices, and public policies aimed at the energy transition in Ceará and Brazil.

III. Literature Review

This theoretical framework addresses the importance of Green Hydrogen in the face of the climate crisis and is organized into three subtopics. The first focuses on the state of the art of Green Hydrogen. The second discusses the quality of teaching Natural Sciences and their Technologies, as well as Mathematics and its Technologies in Brazil, with a special emphasis on Ceará. The third explores the training plan and the strengthening of the renewable energy production chain in Ceará (H-TEC).

Brief State of the Art on Green Hydrogen

Green hydrogen, produced through water electrolysis using renewable electricity, has become a cornerstone of the global transition toward a low-carbon economy. It serves as a clean energy carrier capable of decarbonizing industries, enabling energy storage, and driving sustainable innovations across various sectors, particularly in electric mobility.

As a subject of study within Brazilian Basic Education, understanding the production of this energy vector offers an interdisciplinary approach grounded in principles of physics, chemistry, and mathematics. According to the National Common Curricular Base (BNCC), scientific literacy, critical thinking, and practical skills are essential for preparing students for the workforce, especially within the context of a green economy.

The BNCC also highlights the importance of developing competencies that enable students to investigate, analyze, create, and solve problems in a critical and innovative manner. The study of green hydrogen within Basic Education promotes sustainability, aligns with the Sustainable Development Goals (SDGs), and equips students with knowledge applicable to the job market. It integrates science, technology, engineering, and mathematics (STEM) disciplines while fostering an ethical perspective on environmental responsibility (UNESCO, 2017).

Teaching Natural Sciences and Their Technologies, and Mathematics and Their Technologies in Brazil, with a Focus on Ceará

Over the past two decades, the teaching of Natural Sciences and Mathematics in Brazil has witnessed significant advancements, yet persistent challenges remain. According to various studies, disparities in educational quality remain evident among states and regions, reflecting broader social and economic inequalities (Oliveira & Alvim, 2020). Research highlights the need for better teacher training, updated curricula aligned with global standards, and a more effective allocation of resources to underperforming areas.

Nardi (2017) emphasizes the importance of aligning science and mathematics education with contemporary societal demands, while Alencar (2021) advocates for deeper integration of scientific literacy into teaching methodologies, preparing students to face future challenges. These findings underscore the importance of targeted policies to address regional disparities. In this context, the progress in the performance of public school students in the state of Ceará deserves particular attention.

According to the 2023 Basic Education Development Index (IDEB), the 10 best-performing public municipal elementary schools in Brazil are located in this state. Nevertheless, it is crucial to acknowledge that progress has not been uniform nationwide. Some regions still face significant challenges in educational infrastructure, access to technology, and continuous teacher training. To ensure more equitable education, strengthening collaboration between federal, state, and municipal governments is essential. Promoting innovative initiatives that foster inclusion, enhance teaching quality, and value the teaching profession will pave the way for building a solid foundation for sustainable development and reducing inequalities in Brazil (Plácido et al., 2024).

Moreover, an aspect requiring attention is the role of technology in teaching Sciences and Mathematics. The adoption of digital tools and interactive resources has the potential to transform pedagogical practices, making learning more dynamic and accessible. However, this integration still faces barriers, such as inadequate infrastructure in many schools and the need for teacher training to effectively use these tools. Investments in educational technologies can not only expand access to knowledge but also contribute to preparing a generation better equipped to face the challenges of an increasingly technological and globalized world (Cavalcanti & Silva, 2021).

Training and Strengthening Plan for the Renewable Energy Production Chain in Ceará (H-TEC)

Amid the climate crisis and increasing challenges in energy production and the development of technologies aimed at reducing atmospheric gas emissions, the Government of the State of Ceará launched the Training and Strengthening Plan for the Renewable Energy Production Chain in Ceará (Ceará, 2024).

This strategic initiative seeks to advance a sector with immense potential, particularly due to the state's abundant natural resources, such as wind and solar energy. The expansion in this area drives employment and income generation while fostering the development of a sustainable and innovative production chain, with a particular focus on creating a Green Hydrogen hub (Diário do Nordeste, 2023).

The plan, known as H-TEC, outlines a robust program of technical training and scientific and practical specialization, aiming to train approximately 13,500 students and professionals to work in wind energy, photovoltaic solar energy, and green hydrogen sectors (Ceará, 2024).

The objective is to develop a workforce aligned with market demands and technological innovations, preparing Ceará to establish itself as a reference hub for renewable energies in Brazil and globally. H-TEC is the result of a strategic partnership involving various stakeholders, including the Government of Ceará, the Federation of Industries of the State of Ceará (FIEC), and technical and higher education institutions. Partners include the Ceará Foundation for Scientific and Technological Development (FUNCAP), the Technological Education Center Institute (CENTEC), the Federal Institute of Education, Science, and Technology of Ceará (IFCE), the Secretariat of Science, Technology, and Higher Education of Ceará (SECITECE), the Secretariat of Economic Development (SDE), the Secretariat of Labor (SET), the Secretariat of Education (SEDUC), the National Industrial Learning Service – Regional Department of Ceará (SENAI-CE), the Federal University of Ceará (UFC), and the State University of Ceará (UECE) (Ceará, 2024).

In addition to boosting the energy sector, the plan underscores Ceará's commitment to combating climate change by promoting the transition to a sustainable energy matrix. The training of specialized professionals and the creation of an innovation ecosystem directly contribute to attracting new investments and consolidating the state as a leader in clean energy production. This project represents a milestone in building a greener and more competitive future, reaffirming Ceará's role as a pioneer in Brazil's sustainability and economic development agenda (UNESCO, 2017; ASCOM, 2024).

IV. Conclusion

The study Green Hydrogen and Education: Ceará's Role in Brazil's Energy Transition has fully achieved its objectives, providing a comprehensive analysis of the relationship between education, science, and technology in the context of the energy transition, with a focus on green hydrogen (H2V).

Through a qualitative approach, based on bibliographic and documentary research, it is possible to explore the advances, challenges, and opportunities related to the integration of H2V into educational and technical training in the State of Ceará.

The theoretical foundation, under the subtopic Modern Green Hydrogen, emphasized the strategic importance of H2V in the global energy scenario, highlighting its role as a crucial solution for decarbonization and the strengthening of a sustainable economy. Additionally, the most recent scientific and technological advances were presented, alongside Brazil and Ceará's leadership in the development of this technology, given their geographical conditions and renewable energy infrastructure.

The subtopic Teaching of Natural Sciences and Technologies, Mathematics and Their Technologies in Brazil, especially in Ceará emphasized the importance of basic education as a foundation for training specialists capable of working in the renewable energy sector. Despite the progress made through educational reforms in Ceará, there remains a significant gap in the integration of specific content on H2V and related technologies in the curriculum. Reinforcing these principles, along with the use of proactive approaches and the creation of educational materials focused on sustainability, has proven essential in adapting educational systems to meet the needs of a low-carbon economy.

Finally, the subtopic Training and Strengthening the Renewable Energy Production Chain in Ceará (H-TEC) highlighted the relevance of this program in training a skilled workforce for the renewable energy sector. H-TEC is analyzed as a promising model for public policy in technical training, emphasizing its contribution to building a robust and competitive market around green hydrogen.

The research underscored the potential impact of this initiative not only on strengthening the production chain but also on Ceará's leadership as a reference in Brazil's energy transition. Looking ahead, it is suggested that empirical studies be conducted to assess the effectiveness of educational initiatives and programs like H-TEC in preparing students for the renewable energy job market.

Additionally, interdisciplinary research exploring the development of innovative agile methodologies for teaching Natural Sciences and Mathematics, aligned with the demands of a sustainable economy, could significantly contribute to the advancement of this field. Research into public policies that expand the implementation of programs like H-TEC in other Brazilian states is also deemed relevant for spreading knowledge and promoting an inclusive and nationally-reaching energy transition.

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