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LOW-CARBON INITIATIVES IN THE PULP AND PAPER INDUSTRY AND THE CONTRIBUTIONS TO THE CARBON MARKET IN BRAZIL: AN ANALYSIS OF SUSTAINABILITY REPORTS

INICIATIVAS DE BAIXO CARBONO NA INDÚSTRIA DE CELULOSE E PAPEL E AS CONTRIBUIÇÕES PARA O MERCADO DE CARBONO NO BRASIL: UMA ANÁLISE DE RELATÓRIOS DE SUSTENTABILIDADE

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ABSTRACT

Purpose: This paper analyzes the low-carbon initiatives of Brazilian pulp and paper companies, highlighting their relevance to the national carbon market.

Methodology/Approach: The adopted method consists of documentary research, using secondary data from sustainability reports and institutional websites of the pulp and paper companies studied. The study analyzed the five largest companies in the sector in Brazil.

Findings: The pulp and paper companies analyzed adopt low-carbon practices, such as emission inventory, eco-efficient operations, replacement of fossil fuel-based products, sustainable products, and biomass utilization. In the carbon market, they operate through certifications, carbon sequestration projects, and credit sales.

Research, practical & social implications: The study provides a detailed analysis of the decarbonization strategies adopted by companies in the pulp and paper sector, establishing a robust theoretical basis for understanding low-carbon economy practices.

Originality/ Value: By demonstrating paths to sustainability, this work offers guidelines for companies within and outside the pulp and paper sector, driving the adoption of more environmentally friendly practices.

Keywords: low-carbon economies; carbon-neutral companies; carbon market; net-zero emissions practices.

RESUMO

Objetivo: Este artigo analisa as iniciativas de baixo carbono de empresas brasileiras de papel e celulose, destacando sua relevância para o mercado nacional de carbono.

Metodologia/Abordagem: O método adotado consiste em uma pesquisa documental, utilizando dados secundários de relatórios de sustentabilidade e sites institucionais das empresas de papel e celulose estudadas. O estudo analisou as cinco maiores empresas do setor no Brasil.

Resultados: As empresas de papel e celulose analisadas adotam práticas de baixo carbono, como inventário de emissões, operações ecoeficientes, substituição de produtos à base de combustíveis fósseis, produtos sustentáveis e utilização de biomassa. No mercado de carbono, elas atuam por meio de certificações, projetos de sequestro de carbono e venda de créditos.

Contribuições, implicações práticas e sociais: O estudo oferece uma análise detalhada das estratégias de descarbonização adotadas por empresas do setor de papel e celulose, estabelecendo uma base teórica robusta para compreender as práticas de economia de baixo carbono.

Originalidade/Valor: Ao demonstrar caminhos para a sustentabilidade, este trabalho oferece norteadores para empresas dentro e fora do setor de papel e celulose, impulsionando a adoção de práticas mais amigáveis ao meio ambiente.

Palavras-chave: economias de baixo carbono; empresas carbono zero; mercado de carbono; práticas de zero emissões líquidas.

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1. INTRODUCTION

Current society is engaged in an extensive battle to reduce climate change and its negative impacts on the environment. This issue is exacerbated by the substantial emissions of greenhouse gases (GHG), with carbon dioxide (CO₂) accounting for about three-quarters of these emissions (Huaman; Jun, 2014). Mitigating climate change involves a significant reduction in CO₂ emissions. One approach to achieving this is to use renewable energy sources that produce minimal or zero CO₂ emissions. CO₂ emissions can also be reduced by minimizing process-related emissions and implementing efficient energy storage methods (HO, 2022).

Since the beginning of the industrial era, the atmosphere has witnessed an increase in the concentration of GHGs such as carbon dioxide, methane, and nitrous oxide. This increase has played a significant role in global warming and climate change. The pulp and paper industry is one of the major sources of GHG emissions, resulting from a variety of activities, such as energy consumption, chemical processes, and transportation (Patel et al., 2023). According to Patel et al. (2023), in recent years, the pulp and paper industry has undergone significant changes to meet the new demands and pressures of the modern world. The increasing consumption of paper, growing environmental awareness, and economic instability have driven the development of technological innovations focused on improving energy efficiency. A shining example of sustainability, the Brazilian pulp and paper sector generates a remarkable 88% of its energy from renewable sources (IBÁ, 2022). Moreover, it offers a portfolio of over 5,000 bioproducts derived from renewable resources, these being carbon-storing, recyclable, and biodegradable (IBÁ, 2022).

For this research, a comparative analysis will be made of the low-carbon initiatives in the five largest pulp and paper companies operating in Brazil. In addition, the low-carbon initiatives that these companies have adopted and how they can generate carbon credits will be analyzed. With this in mind, the objective of this work is to analyze the initiatives of pulp and paper companies to reduce carbon emissions and how this affects the national carbon market. The operations of these companies can help to reduce carbon emissions and, consequently, they can be inserted into the carbon market generating extra income for the company, and increasing the supply of carbon emissions, because, in the opportunity to capture carbon, companies also evaluate a commercial opportunity in this surplus. We chose this sectoral cut because these companies have the opportunity to operate in carbon capture and sale of carbon credits in the voluntary market.

This research delves into the decarbonization strategies employed by companies in the pulp and paper sector, aiming to achieve greater sustainability in their operations.

By analyzing these strategies in detail, we establish a strong theoretical foundation for understanding low-carbon economy practices. This knowledge is then leveraged to offer practical guidance for companies both within and outside the pulp and paper sector, ultimately driving the adoption of more environmentally friendly practices. In the current climate scenario, market demands necessitate innovation without compromising environmental responsibility. This has led organizations to invest heavily in research and development (R&D) activities focused on the production of sustainable products. Furthermore, the study outlines the goals of these companies in meeting both market and environmental requirements.

The work also identifies and analyzes the participation of companies in the carbon market, examining their entry strategies and level of involvement. This includes addressing whether they act as buyers, sellers, or both. By demonstrating clear paths to sustainability, this research offers valuable contributions to both the academic and industrial sectors. This knowledge empowers companies to make informed decisions about their sustainability strategies, ultimately contributing to a more environmentally conscious and responsible future.

The rest of this article has the following structure. Section 2 outlines the literature review, providing a consistent theoretical basis for the study. Section 3 details the research method used and the procedures adopted in data collection and analysis. The results obtained are presented in Section 4, followed by the analysis and discussion of these in Section 5, where the implications and meanings of the findings are explored in the existing literature. Finally, Section 6 offers the final considerations of the article, synthesizing the findings, highlighting contributions to the field of study, and suggesting directions for future research.

2. LITERATURE REVIEW

2.1 Low-carbon practices in the pulp and paper industry

The pulp and paper sector comprises three distinct industries: pulp, paper, and paper products, forming the production chain along with forests, the publishing and printing industry, and distributors (Montebello & Bacha, 2013). The pulp industry produces pulp and high-yield pulp, which can be sold domestically or internationally, or used internally for paper production (Montebello & Bacha, 2013). The paper industry encompasses various types, such as newsprint, printing and writing paper, packaging, sanitary paper, and cardboard, among others (Montebello & Bacha, 2011).

Cellulose has variations, such as long and short fiber, with the former being more

resistant and usually derived from pine wood, while short-fiber cellulose, known for its higher absorbent capacity, is extracted from eucalyptus, where Brazil leads global production (Montebello & Bacha, 2013). High-yield pulp can be obtained from both types of wood (EPE, 2022).

The evolution of the pulp industry has primarily met external demands, while the paper and paper products industry has focused on the domestic market in the last five decades (Montebello & Bacha, 2011). Production in 2021 reached 22.5 million tons of pulp and 10.7 million tons of paper, positioning Brazil as the second-largest producer, behind the USA (IBÁ, 2022). IBÁ represents about 50 companies in the production chain, emphasizing the cultivation of pine and eucalyptus on 9.93 million hectares in 2021 (IBÁ, 2022).

The sector faces environmental challenges, being a significant consumer of water resources (82% restored after treatment) and responsible for over 16% of industrial energy consumption in Brazil (EPE; IEA; IBÁ, 2022). Companies are adopting sustainable practices for energy efficiency and reducing greenhouse gas emissions (EPE; IEA; IBÁ, 2022).

The implementation of a low-carbon emission supply chain is crucial for a sustainable economy, internationally recognized as an essential strategy in the face of climate change (Zhang et al., 2015). Despite the increase in renewable fuels, the sector still relies on fossil fuels, emitting a substantial amount of carbon dioxide, making decarbonization vital for climate stabilization (Lipiäinen et al., 2022).

The transition to a sustainable economy requires specific public policies and regulations, as well as an internal cultural shift within companies (Lazaro, 2010). In Brazil, in-depth knowledge of legislation is essential, covering incentives and penalties (Lazaro, 2010). Considering the net carbon absorption and the paper production chain, Man et al. (2020) identified greenhouse gas emissions ranging from 1.96 to 6.55 t CO₂ eq/t paper, emphasizing the need for low-carbon practices.

2.2 Carbon market in Brazil

The carbon market, a new global financial market, assigns a monetary value to greenhouse gas emissions (GHG), which cause damages such as rising sea levels, extreme weather events, and impacts on human health (Lyu et al., 2020; Sobrinho, 2023). Imposing a cost on emissions discourages polluting activities and drives solutions for their reduction (Sobrinho, 2023). Essential in the transition to a green economy and the pursuit of carbon neutrality, the carbon market provides financial incentives for sustainable

investments, contributing to emission reduction goals and supporting vulnerable communities (ICAP, 2023).

Since the ratification of the Kyoto Protocol in 1997, which set GHG reduction targets for developed nations, the carbon market has gained prominence (Vargas et al., 2021). The main carbon pricing instruments are emissions trading and taxation (Sobrinho, 2023). The Protocol established the Clean Development Mechanism (CDM) in 2005, allowing developing countries to implement emission reduction projects (Latimer & Maume, 2015; Vargas et al., 2021).

There are two types of carbon markets: regulated and voluntary, both trading credits representing a ton of CO₂ avoided or offset (Latimer & Maume, 2015; Vargas et al., 2021). Regulated markets, coordinated by governments, compel companies to participate, while voluntary markets involve voluntary choices by companies and individuals (Latimer & Maume, 2015). Chile is the only country in Latin America with a mandatory emission trading system, covering about 30% of national emissions (ICAP, 2023).

In Brazil, the regulated carbon market is in development, with a bill for the Brazilian Emissions Trading System (SBCE) under discussion (Sobrinho, 2023). The expectation is to regulate the national market for transparency and legal certainty, but technical details will come later through decrees and resolutions (Munhoz, 2023). It is estimated that the delay in regulation could cost Brazil up to 25 billion euros per year (Sobrinho, 2023).

In the voluntary market, Brazil is the fourth-largest producer of carbon credits, prominently in the Agriculture, Forestry, and Other Land Uses (AFOLU) sector, responsible for 73% of credits generated in 2021 (Vargas et al., 2021). Pulp and paper companies play a crucial role in sustainable forest management and carbon sequestration, contributing to credit generation in the carbon market (Hu et al., 2023).

3. METHODOLOGY

Sustainability reporting has been a practice adopted by numerous companies, considered an important document for the development of a more congruent relationship between society and the environment, as it can be a means to provide greater transparency and integrity about the organization's sustainable performance (Campos et al, 2013). Given the importance of this topic, this article conducted a secondary data collection from sustainability reports of 5 (five) industries in the pulp and paper segment. The main information about these companies was gathered in Table 1. The companies were chosen

considering their respective profitability and for having a significant influence on the country's economy. In addition to these criteria, the companies were also selected based on their commitment to sustainability. All five companies have set net-zero emissions targets for 2050 or earlier. The companies also have different levels of involvement in the carbon market. Two of the companies are currently trading carbon credits, while the other three are considering entering the market.

Table 1

Company characterization

Codename	Company A	Company B	Company C	Company D	Company E
<i>Name</i>	Bracell	International Paper	Irani	Klabin	Suzano
<i>Origin</i>	Brazilian	American	Brazilian	Brazilian	Brazilian
<i>Year of foundation</i>	2019	1898	1941	1989	1924
<i>Revenue (R\$)</i>	-	10,3 billion	228,7 million	5,083 billion	22,6 billion
<i>Number of operations (Brazil)</i>	4	3	4	22	11
<i>Number of employees</i>	2867	49300	2200	9000	35000
<i>Reports analyzed</i>	Bracell SP Celulose LTDA (2023)	International Paper (2022), International Paper (2023a), and International Paper (2023 b)	Celulose Irani S.A. (2023a), and Celulose Irani S.A. (2023b)	Klabin. (2022), Klabin (2023a), Klabin (2023b), Klabin (2023c), and Klabin. (202d)	Suzano S.A. (2021), Suzano S.A. (2023a), and Suzano S.A. (2023b)

Sustainability reports are documents that provide information about the environmental, social, and economic practices of companies. Both the sustainability reports and environmental, social, and corporate governance (ESG) reports refer to the latest data released, relating to the year 2022, made available on the institutional websites of the respective companies. They are documents that allow the collection of data relevant to the initiatives and sustainable practices of this sector, covering information on carbon emissions and the company's role in the current Brazilian carbon market, among other reports.

To contribute to the interpretation of data from these sources, information was used from technical and informative studies available in the literature on the pulp and paper sector in Brazil. The research also sought, through qualitative procedures, to carry out a broad bibliographic review and documentary analysis.

In this study, it was relevant to analyze the data from the reports using the content analysis method, as according to Bardin (page 37, 2011), "content analysis is a set of

communication analysis techniques", not being an instrument, but rather a range of them. The content analysis represents the handling of messages or the treatment of content and expression of such content, to reveal the indicators that allow understanding about another context that is not that of the message. That is, to identify patterns and trends in the content, and to understand the meaning and implications of the content (Bardin, 2011).

The analysis of the sustainability reports unfolded in two phases: individual analysis and cross-analysis. During the individual analysis phase, a multifaceted approach was adopted. Specific keywords related to low-carbon practices and the carbon market, such as "renewable energy," "water conservation," "carbon credits," and "offset projects," were meticulously searched for in each report. This extracted data was then categorized into relevant themes, like "decarbonization initiatives" and "carbon market performance". Finally, thematic analysis delved deeper, identifying broader patterns and trends within these categories. This phase revealed fascinating insights, such as the prevalence of decarbonization initiatives across the companies and their varied performance in the Brazilian carbon market. Following the individual analysis, a cross-analysis was conducted, as described by Strauss and Corbin (2008), to compare and organize the extracted data in search of commonalities and divergences, specifically focusing on similarities and differences in low-carbon practices and carbon market strategies across the companies. This involved utilizing a combination of tables, matrices, and qualitative analysis.

4. RESULTS

In this results section, the main goals, processes, and practices employed by each investigated company to reduce their environmental impact are explored, as well as their performance in the carbon market, providing a comprehensive overview of the strategies adopted in the context of the low-carbon economy in Brazil. All data analyzed were obtained from the 2022 sustainability reports of each company, as well as information available on their respective institutional websites.

In pulp and paper companies, sustainability efforts are gaining traction, reflected in the growing adoption of sustainable programs and reports. As shown in Table 2, all companies demonstrate a comprehensive commitment to sustainability by actively participating in initiatives and reports that address environmental, social, and governance issues. Programs include participation in the Carbon Disclosure Project (CDP), Task Force on Climate-Related Disclosures (TCFD), U.S. Environmental Protection Agency Mandatory Reporting Rule, European Union Emissions Trading System, Global

Reporting Index (GRI), GHG protocol, Science Based Targets Initiative (SBTi), Intergovernmental Panel on Climate Change, and Sustainability Accounting Standards Board (SASB). This shows best practices in ESG disclosure and management, showcasing their dedication to corporate responsibility, environmental impact mitigation, and enhanced transparency and accountability towards their stakeholders.

Table 2

ESG programs and report

ESG programs and reports	Company A	Company B	Company C	Company D	Company E
<i>Carbon Disclosure Project (CDP)</i>	X	X	X	X	X
<i>Task Force on Climate-Related Disclosures (TCFD)</i>	X	X	X	X	X
<i>U.S. Environmental Protection Agency Mandatory Reporting Rule</i>	-	X	-	-	-
<i>European Union Emissions Trading System</i>	-	X	-	-	-
<i>Global Reporting Index (GRI)</i>	X	X	X	X	X
<i>GHG protocol</i>	X	X	X	X	X
<i>Science Based Targets Initiative (SBTi)</i>	X	X	X	X	X
<i>Intergovernmental Panel on Climate Change</i>	X	X	X	X	X
<i>Sustainability Accounting Standards Board (SASB)</i>	X	X	X	X	X

Aligned with the United Nations' global Sustainable Development Goals (SDGs), all companies have embedded ESG commitments in their strategies. These commitments and goals are focused on pursuing sustainability through innovation and the optimization of operational processes. Company D has already categorized its goals using the (SDGs), while the remaining goals of the other companies were separated by the authors of this study. Table 3 provides an overview of the SDGs found (SDG6 – Clean water and sanitation; SDG7 – Affordable and clean energy; SDG8 – Decent work and economic growth; SDG11 – Sustainable cities and communities; SDG12 – Responsible consumption and production; SDG13 – Climate action; SDG14 – Life below water; SDG15 – Life on land) separated by companies.

Driven by their commitment to ESG goals and achieving net-zero status, companies are actively implementing diverse sustainable practices and fostering continuous innovation. Table 4 provides a comparative analysis of the low-carbon strategies adopted by five leading pulp and paper companies in Brazil.

Table 3

Company goals and SDG corresponding to each

	Company A	Company B	Company C	Company D	Company E
SDG6	-	-	Reduce water consumption per ton produced by 30% by 2030.	100% of the locations where we operate with initiatives to increase territorial water security. 100% of forestry operations under own management with hydro-solidarity management. Reduce specific industrial water consumption by 20%.	Reduce water collected in industrial operations by 15% by 2030. Increase water availability in all critical river basins in Suzano’s operating area by 2030*.
SDG7	Commercially operate your thermoelectric plant, capable of generating 100% renewable clean energy, through turbogenerators (SDG7 and SDG8).	-	Be self-sufficient in renewable energy generation by 2030. -Generate 273 thousand certified carbon credits in the period 2020-2030.	92% share of renewable sources in the energy matrix. 100% purchase of certified energy from renewable sources.	Increase renewable energy exports by 50% by 2030.
SDG8		-	-	-	Make 10 million tons of products of renewable origin available, which can replace plastic and other petroleum derivatives by 2030.
SDG11	-	-	-	100% of priority municipalities with participatory management encouraged.	-
SDG12	Commercially operate your thermoelectric plant, capable of generating 100% renewable clean energy, through turbogenerators. Low carbon production. They have been drawing up plans, policies, and actions to mitigate GHG emissions.	-	Zero waste sent to landfill by 2030	100% of critical suppliers are covered by the Sustainable Supply Chain Management Program	Reduce the volume of industrial solid waste sent to landfill by 70% by 2030. Remove 40 million tons of carbon equivalent from the atmosphere by 2025. Reduce the intensity of scope 1 and 2 GHG emissions by 15%, per ton of production by 2030.
SDG13	Commercially operate your thermoelectric plant, capable of generating 100% renewable clean energy, through turbogenerators. Low carbon production. They have been drawing up plans, policies, and actions to mitigate GHG emissions.	Reduce our scope 1, 2, and 3 GHG emissions by 35%.	Increase the positive balance between GHG emissions and removals by 20%. Generate 273 thousand certified carbon credits in the period 2020-2030.	Reduce scope 1 and 2 GHG emissions by 25% per ton of cellulose, paperboard, and packaging by 2025, and 49% per ton by 2035. Net capture of 45 million tons of CO2 eq from the atmosphere between 2020 and 2030.	Remove 40 million tons of carbon equivalent from the atmosphere by 2025. Reduce the intensity of scope 1 and 2 GHG emissions by 15%, per ton of production by 2030. Increase the export of renewable energy by 50% by 2030.
SDG14		Reduce our water use by 25% and implement context-based water management plans across all factories.	-	-	-
SDG15	Low carbon production, outlining plans, policies, and actions to mitigate GHG emissions (SDG14 and SDG15).	Conserve and restore 400,000 hectares of forest. Promote circular solutions throughout our value chain and create innovative products that are 100% reusable. Source 100% of our fiber from sustainably managed forests or reclaimed fiber.	-	Map wildlife hotspots to minimize accidents. Enhance forest-dependent fauna species, fostering a minimum of 6 partnerships/research annually focused on nature conservation and biodiversity. Reintroduce 2 locally extinct species and reinforce the populations of 4 threatened species. Provide 1 million native tree seedlings for the restoration of degraded areas.	Connect, through ecological corridors, 500 thousand hectares of Cerrado, Atlantic Forest, and Amazon fragments by 2030.

Table 4

Low-carbon and sustainable practices for reducing GHG emissions

Low-carbon and sustainable practices	Company A	Company B	Company C	Company D	Company E
<i>Net zero Company</i>	X	X	X	X	X
<i>Emission inventory</i>	X	X	X	X	X
<i>Eco-efficient operations</i>	X	X	X	X	X
<i>Replacement of fossil fuel-based products</i>	X	X	X	X	X
<i>Sustainable products</i>	X	X	X	X	X
<i>Waste recycling</i>	X	X	X	X	X
<i>Biomass utilization</i>	X	X	X	X	X
<i>Investment in R&D to minimize emissions</i>	X	X	X	X	X
<i>Open innovation to minimize emissions</i>	-	-	X	X	X
<i>Management of suppliers' sustainable practices</i>	X	X	X	X	X
<i>Prioritization of purchases from local suppliers</i>	X	X	X	X	X
<i>Reduction of transportation emissions</i>	X	X	X	X	X
<i>Climate risk management</i>	X	X	X	X	X
<i>Adoption of climate initiatives</i>	X	X	X	X	X
<i>Environmental communication and education actions</i>	X	X	X	X	X
<i>Variable remuneration linked to ESG targets</i>	-	-	X	X	X
<i>Voluntary long-term targets</i>	X	X	X	X	X

Company A's sustainability strategy is based on six pillars, focused on environmental, social, and governance issues. The three main pillars address environmental themes, namely "Climate" focuses on positive impacts, "Climate Change" aims at low-carbon production, and "Biodiversity and Landscapes" favoring ecosystems.

The "Climate" pillar seeks energy efficiency, highlighting the generation of clean and renewable energy, as exemplified by the commercial operation of its thermal power plant. Its production lines have the approval of the Electric System Operator and the National Electric Energy Agency (Aneel) to commercially operate its thermal power plant, capable of generating 100% clean energy. In addition, the future Tissue paper factory will be 100% automated, operating without fossil fuels. The "Climate Change" pillar reflects Company A's commitment to reducing GHG emissions, highlighting the significant carbon stock in its forest areas and participation in initiatives such as TNFD Brazil and the Net Zero Movement. Regarding the "Biodiversity and Landscapes" pillar, Company A is committed to conserving one hectare of native vegetation for every hectare of planted eucalyptus. It also supports the conservation of public areas and the recovery of degraded areas. Other sustainable practices implemented in the company are the

evaluation and selection of suppliers by environmental legislation, the preservation of water and watersheds, as well as for the reduction of consumption, and the increase in reuse.

Company B is a global paper and packaging company with over a century of history. The company is committed to sustainability and has a range of low-carbon practices in place. One of Company B's key low-carbon practices is the replacement of fossil-based products with more sustainable sources. The company uses carbon-neutral biomass and production waste to generate energy at its factories. In addition, it dedicates 25% of its planted area to conservation. To mitigate climate risks, Company B conducts detailed climate scenario analyses and invests in R&D for innovations in processes, equipment, and products. The company also works with customers to offer more sustainable and lightweight packaging solutions.

In terms of transportation, Company B prioritizes the purchase of local suppliers and promotes the use of alternative fuels. The company is also investing in efficient production technologies and operating with a significant portion of energy from biomass waste. Company B also invests in technologies that can be sold and used by other companies. One example is the MasterDesign platform, which is used to share packaging designs and inspire ideas and creativity. Another innovative Company B's technology is the Secure Box, a package designed with an inviolable seal that breaks when opened for the first time. The box is made entirely of recycled corrugated cardboard and eliminates the need for adhesive tape or other materials, significantly reducing the environmental impact of packaging waste.

Company C incorporates a variety of low-carbon practices into its operations, demonstrating a strong commitment to sustainability. With a positive carbon balance, its forest areas, both native and planted, capture more CO₂ than the emissions generated during its industrial operations. The company's ambitious goal of achieving energy self-sufficiency by 2030 includes plans to expand hydroelectric power generation and explore innovative alternatives for renewable energy production. Consistent investments in forest restoration projects reinforce Company C's commitment to nature conservation and effective carbon capture.

In the context of sustainable development, Company C focuses its efforts on research and development to create sustainable packaging as an alternative to plastics. Recognized as one of the leading producers of sustainable paper packaging in Brazil, its products stand out for being 100% recyclable and derived from renewable natural resources. The commitment to eco-efficient innovation is evident in the company's

investment in sustainable technologies. It adopts a comprehensive approach, from the creation of a Corporate Venture Capital (CVC) program to partnerships and direct acquisitions of startups. Prioritizing solutions that contribute to the reduction of natural resource consumption, energy efficiency, and waste management, the company is constantly at the forefront of sustainable practices. In addition to internal initiatives, Company C stands out for its involvement in environmental education actions, benefiting schools, employees, and local communities. By promoting the reuse of solid waste and reducing the generation of effluents, the company contributes to a holistic approach to sustainability. The encouragement of employee creativity through the "Inova Ideias" program demonstrates Company C's commitment to fostering ideas that drive improvements in products, processes, and results.

Company D adopts low-carbon practices, exemplified by the "ImPacto NetZero" project in partnership with the UN Global Compact's Brazil Network, aiming to engage companies and society in the pursuit of a more sustainable world. The company aims to reduce 20% of Greenhouse Gas (GHG) emissions from 2010 to 2022, as outlined in its sustainability report. To prevent unchecked deforestation, Company D maintains Private Natural Heritage Reserves (RPPNs) in the states of Paraná and Santa Catarina, totaling nearly 9 thousand hectares dedicated exclusively to scientific research, environmental protection, and preservation of natural resources. The preservation of these areas contributes to conserving the biodiversity of the Mata Atlântica biome, housing various endangered species. Another example is the Controlled Wood Program, which ensures the origin of wood from independent suppliers. Suppliers undergo assessments based on Forest Stewardship Council (FSC) criteria, including economic management, environmental compliance, and social impacts. To support tree planting, Company D invested in the genetic improvement of pine and eucalyptus for easy multiplication. Satellite and drone monitoring ensures the integrity of the planted areas.

Additionally, the company has initiated the use of electric trucks in the interior of São Paulo for deliveries, aiming to avoid the use of fossil fuels. In the initial phase, four electric trucks are being tested. This initiative is a collaboration with Grupo LOG, a long-term partner, aiming to reduce greenhouse gas emissions in scope 3. Another sustainable project involves the creation of green products such as Eukaliner and Klacup, developed by the company to avoid the use of virgin raw materials or unnecessary waste. Eukaliner is a highly innovative kraftliner paper made exclusively from eucalyptus fibers, offering advantages such as reduced grammage, improved print quality, and steam savings, resulting in more robust and structured corrugated cardboard packaging, becoming the

primary choice in the market. KlaCup is a recyclable product made of paperboard designed for cups, with pine and eucalyptus fibers providing strength and print quality. A barrier allows for various applications, including direct contact with hot or cold food.

Company E has various low-carbon practices and strategies in its operations and product manufacturing. It focuses on replacing fossil-based products with renewable alternatives, aiming to reduce greenhouse gas emissions. Furthermore, Company E's bioeconomy strategy aligns with global trends in low-carbon economies, emphasizing areas such as lignin, bio-oil, nanocellulose, and biocomposites, which offer more sustainable alternatives compared to fossil-based products. The company has established strategic partnerships, including collaboration with Spinnova, a Finnish startup, for the production of 100% renewable textile fibers from microfibrillated cellulose.

Company E employs technologies and practices to ensure its forests are sustainably managed, utilizing a forest management system called "Direct Planting" that avoids deforestation and burning, preserving biodiversity and soil quality. Additionally, the company takes a proactive approach to climate risk management, identifying priority risks such as forest productivity loss due to changes in the hydrological cycle and developing mitigation strategies, including scenario modeling and optimizing clone allocation to address adverse conditions. Company E also invests in innovation and R&D to create low-carbon products, such as papers for food contact and sustainable primary and secondary packaging, reducing reliance on plastics and promoting eco-friendly alternatives.

The company invests in sustainable transportation technologies, exploring options such as electric vehicles and lower-carbon fuels to optimize the efficiency of its logistics chain. In wood transportation, Company E implements projects to reduce the average radius, optimize transport modes, and increase vehicle payload capacity, such as compositions of six semitrailers, reducing the number of necessary trips and making transportation more efficient and sustainable. Furthermore, it emphasizes strategic communication and education, aiming to raise awareness among stakeholders and employees about the importance of climate change and sustainable practices.

Sustainable business practices are increasingly being adopted by companies to position themselves proactively in the carbon market, seeking opportunities for revenue generation and cost reduction. The adoption of renewable energy sources, such as biomass, solar, and wind energy; waste reduction through recycling practices; the development of sustainable products and services, such as recycled paper and compostable packaging, and investment in sustainable forests, which are managed in a

way that preserves biodiversity and captures carbon, are some of the practices that can contribute to the reduction of greenhouse gas emissions and the generation of carbon credits (Table 5).

Table 5

Performance of pulp and paper companies in the Brazilian voluntary carbon market

Company	Credit Sales	Carbon Market Plans
<i>Company A</i>	No	Although there are no confirmed plans, the evidence suggests that it is considering participating in the carbon market.
<i>Company B</i>	Yes	It has been trading carbon credits in the voluntary market, primarily international, since 2008.
<i>Company C</i>	Yes	It has been trading carbon credits in the Brazilian voluntary market since 2006.
<i>Company D</i>	No	It commits to purchasing voluntary carbon credits to offset emissions while also developing a project for future carbon credit entry and trading.
<i>Company E</i>	No	It is not currently selling carbon credits, but it has internally structured to enter the market in the future

Regarding Company A’s participation in the carbon market, there are currently no records of it. However, the company has a project for capturing more CO₂ than emitting it in its operations, culminating in a considerable carbon stock in its forest areas. These, among other demonstrations of positive initiatives in the sustainable area, lead to the consideration that the company is moving towards possible participation in the future.

Company B owns large forest areas in Brazil that capture and store carbon from the atmosphere. The company is also involved in reforestation and forest restoration projects that contribute to the reduction of greenhouse gas emissions. The company entered the carbon market in 2008 with a project that sought to replace the fuel used in two boilers responsible for generating energy for its manufacturing, replacing fuel oil with natural gas. With this project, Company B entered the market by selling \$1.2 million by mitigating the CO₂ generated in the production process.

Company C is a pioneer in the carbon credit market, standing out as the first company in the pulp and paper sector in Brazil to enter this market almost two decades ago. In addition, it was the second in the world to receive carbon credits issued by the Kyoto Protocol. The company achieved this pioneering position by using forest residue biomass as a source of energy for its paper and packaging units in Santa Catarina. One of the main initiatives is the use of forest residue biomass, which was previously deposited in landfills and emitted greenhouse gases. Since 2005, the company has used a boiler to

burn this biomass, generating steam and energy to supply its units, registering the process with the UN as the "Irani Biomass Electricity Generation Project," validated as a Clean Development Mechanism (CDM). In addition, the company has a Small Hydroelectric Power Plant (PCH) and two Hydroelectric Generating Plants (CGHs) with automated control and remote operation, as well as four boilers for thermal energy generation.

Since 2006, Company C has maintained the certificate of Carbon Neutral company and was the first Brazilian company to certify its Greenhouse Gas Emissions Inventory according to the international standard ISO 14.064/2006. The company has been seeking to improve its performance in the carbon market through measures such as increasing energy efficiency in its industrial plants, reducing non-hazardous waste destined for landfills, increasing carbon reservoirs through studies in the soil of its forest base (native and planted) and increasing forest area. One of its main objectives is to generate 273,000 certified carbon credits in the period from 2020 to 2030. The company also stood out with the Wastewater Treatment Plant, which avoids methane emissions and made Irani the first company in Latin America to register a CDM for the treatment of industrial wastewater with the United Nations.

In partnership with the Brazilian Development Bank (BNDES), Company B has initiated a carbon credit acquisition project in the voluntary market. This undertaking focuses on purchasing carbon credits from verified projects in Brazil that demonstrate proven GHG reduction or removal. Within the context of combating climate change, the BNDES is exploring financial instruments and institutional structures to foster the growth of the voluntary carbon market in Brazil. This initiative, which began in March 2022, involves BNDES acquiring carbon credits to stimulate the voluntary market in the country. In contrast, Company D is developing this project to sell carbon credits. The project involves the reforestation of eucalyptus and pine forests and the restoration of native forests. These activities contribute to the reduction of greenhouse gas (GHG) emissions by capturing carbon from the atmosphere and storing it in trees and soil. Once the project is validated by the Clean Development Mechanism (CDM), Company D will be able to sell the carbon credits to other companies or organizations that want to offset their emissions.

Company E is committed to issuing carbon credits in its main sectors: forestry, industrial, and logistics. Internally, the company adopts carbon pricing in its new project analyses, taking into account various regulatory and carbon market scenarios. This allows for the evaluation of the impact of emissions and generates financial indicators that incorporate the shadow price of carbon, influencing investment decisions. The company

adopts various methodologies, such as biological sequestration through the sustainable forest management of eucalyptus cultivation and avoided deforestation methodologies. In 2021, it launched projects such as the "Cerrado Carbon Project," which was audited in 2022, and the "Horizon Carbon Project." These projects not only contribute to the fight against climate change by generating carbon credits, but they also promote social and environmental benefits, such as inclusive recycling actions and honey production. These initiatives play a crucial role in capturing and storing carbon from the atmosphere. The company also establishes partnerships with other companies and organizations to develop carbon reduction and sequestration projects, contributing to the scalability of its initiatives.

The results presented demonstrate the essential role of Brazilian pulp and paper companies in implementing innovative solutions to mitigate climate change. These solutions pave the way for a sustainable future for the sector and the planet. The growing awareness of the importance of sustainability also paves the way for these companies to be crucial in the development of the Brazilian voluntary carbon market and a regulated market in the future.

5. DISCUSSION

In this section, the implications of the initiatives and practices of pulp and paper companies for GHG emission reductions will be analyzed, highlighting the relationships between individual company efforts and their impact on the low-carbon economy in Brazil. Additionally, how emissions in the pulp and paper sector reflect on the dynamics of the national carbon market will be discussed.

5.1 Decarbonization initiatives in the pulp and paper companies

The pulp and paper industry is one of the most energy-intensive industries globally, ranking as the fourth largest industrial energy user (EPE; IEA; IBÁ, 2022; Del Rio et al., 2022). The sector has significant emissions resulting from production and manufacturing processes, in addition to the products having a short life cycle, and most of the carbon generated during paper production is released into the atmosphere within one year (Del Rio et al., 2022). Despite the negative impacts, the sector has been standing out in emission reduction and renewable energy production (Del Rio et al., 2022) through investment in technologies and practices aimed at reducing direct and indirect GHG emissions.

Emissions from the pulp and paper industry can be divided into direct (Scope 1)

and indirect (Scope 2 and 3). Direct emissions are emissions generated as a direct result of the company's operations (ICFA, 2005). In the pulp and paper industry, they come from the energy consumed during forest cultivation and harvesting, and from the burning of fossil fuels and biomass (Zhao et al., 2019). Indirect emissions occur outside the industry's operations, but are attributed to it (Scope 2) or its supply chain (Scope 3) (ICFA, 2005). In this sector, indirect emissions are associated with energy supply processes, transportation of raw materials and products, and the use of products (Zhao et al., 2019). To reduce their emissions, pulp and paper companies are adopting a range of low-carbon practices. In general, the low-carbon practices investigated seek to improve operational efficiency, reduce waste, and minimize dependence on fossil fuels and can be classified into production, product, logistics, and additional practices (Böttcher & Müller, 2015).

Production practices aim to reduce emissions associated with the production of pulp and paper (Böttcher & Müller, 2015). The main strategies adopted by the companies analyzed are the development of eco-efficient operations, through the application of more efficient technologies and processes to reduce energy, water, and other resource consumption; the replacement of fossil fuel-based products with renewable energy sources, and the reuse of waste, such as biomass. These practices are driven by the high investment in R&D that these companies have made, through the creation of research centers, partnerships, and startup acceleration. For example, approximately 77% of Company E's R&D resources in 2020 were allocated to mitigation technologies and low-carbon products, demonstrating the incorporation of climate concerns into the company's strategy.

All companies are developing sustainable products, with renewable raw materials, directly impacting the product development stage (Böttcher & Müller, 2015). These practices include the use of renewable raw materials, such as plantation timber, the development of products with lower environmental impact, and the adoption of more efficient technologies. For example, Company A uses 100% plantation timber to produce pulp and paper; Company D developed KLaCup®, a recyclable paper cup made from cardboard; Company E launched Greenpack®, a food contact paper with a lower environmental impact; and Company C produces sustainable packaging papers from virgin fibers from planted forests.

Logistics and supply chain practices prioritize minimizing emissions throughout the product's lifecycle, from wood procurement to transportation and final use (Böttcher & Müller, 2015). This encompasses diverse strategies like Company D's pioneering use of electric trucks for inland deliveries in São Paulo, Company E's exploration of green

ammonia for transatlantic shipping, and International Paper's collaboration with clients to develop lighter, more efficient packaging. These initiatives not only mitigate environmental impact through reduced transportation emissions but also bolster regional economies by prioritizing locally sourced materials and fostering sustainable practices among suppliers (Dwivedi et al., 2023; Lee, 2012). By embracing such holistic approaches, these companies pave the way for a more sustainable supply chain paradigm.

In addition to the production, product, and logistics strategies, all the companies analyzed have actions that reflect a holistic commitment to sustainability and corporate responsibility (Dwivedi et al., 2023; Lee, 2012). These practices include the establishment of voluntary long-term goals, the transparent communication of their sustainable practices through institutional websites and sustainability reports, the education and training of employees and business partners on the importance of environmental conservation, and the linking of employee variable compensation to environmental, social, and governance goals. These actions demonstrate that the companies analyzed are committed to sustainability in all its dimensions, from operational to cultural (Dwivedi et al., 2023).

Finally, a relevant point is that all the companies analyzed have neutrality in their operations, demonstrating the potential of forests to offset greenhouse gas emissions (Del Rio et al., 2022). This could generate new business opportunities for the forestry sector, such as participation in the carbon market.

5.2 Performance of pulp and paper companies in the Brazilian carbon market

The expansion of the forestry sector in Brazil, driven by state policies and corporate interests, can be understood as part of a broader strategy to meet the growing global demand for biomass and paper products (Fernando et al., 2021). Simultaneously, this expansion is aligned with the objectives of mitigating climate change, contributing to the absorption of GHGs from the atmosphere (Fernando et al., 2021).

Recognizing the considerable potential in mitigating climate change, pulp and paper companies have focused their efforts on reducing GHG emissions through four key pillars (IBÁ, 2023). These pillars range from carbon storage in natural and production forests to carbon removal during the development of these forests, the adoption of renewable energy to reduce emissions, and finally, the storage of carbon in products derived from forest sources (IBÁ, 2023). These initiatives not only contribute significantly to climate change mitigation but also drive the advancement towards a low-carbon economy (Del Rio et al., 2022).

The participation of pulp and paper companies in the voluntary carbon market is

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still incipient, but it has been growing in recent years. According to the Bioeconomy Observatory, the AFOLU sector (Agriculture, Forestry, and Other Land Use) recorded a significant increase in credits generated in 2021, with a growth of 236% compared to 2020 and an increase of 779% compared to 2019 (Vargas et al., 2021). In addition, the sector has considerable potential, with the capacity to reduce 13.8 million tons of CO₂ equivalent (tCO₂e) annually (Vargas et al., 2021). This growth is driven by the high corporate demand to meet carbon neutrality commitments (Vargas et al., 2021). This demonstrates that the actions of pulp and paper companies in the carbon market have become an integral part of their global sustainability strategy (Fernando et al., 2021).

Pulp and paper companies are adopting a variety of strategies to participate in the voluntary carbon market. Company C is a leader in the carbon credit market in the pulp and paper sector, standing out for its innovative use of forest residue biomass in power generation. Certified as Carbon Neutral since 2006, the company reinforces its commitment to sustainable practices, focusing on energy efficiency, waste reduction, and forest base expansion. In 2021, Company C traded 155,885 carbon credits from the "Irani Wastewater Methane Avoidance Project", the world's first fully aerobic wastewater treatment plant. With two CDM projects, including the pioneering Co-Generation Plant, Company C became the first company in the sector in Brazil to obtain carbon credits under the Kyoto Protocol, totaling approximately R\$ 19.5 million. These initiatives consolidate Company C as a reference in sustainable innovation and emission neutralization. On the other hand, Company B is selling its excess carbon credits, starting its journey in 2008 with the change from using fuel oil to natural gas.

Some companies, such as Companies A, D and E are developing reforestation and carbon capture and storage projects and are preparing to enter the carbon market. Company E has developed carbon sequestration projects and intends to remove 40 million tons of carbon from the atmosphere by 2025. Company D is actively participating in discussions about the regulated carbon market. Although the company has already achieved a positive carbon balance, it is committed to intensifying efforts to reduce emissions in its industrial operations. Company D recognizes its significant potential to generate carbon credits and is evaluating several projects, including those related to forest expansion in degraded areas and land use changes that can add additional value to sustainability initiatives. Company A is investing in initiatives to further increase CO₂ capture, such as planting new trees, recovering degraded areas, and sustainable forest management, and in 2022 it generated a surplus of 0.3 million tons of carbon, demonstrating its potential to enter the carbon market. In addition, Company A has been

purchasing carbon credits from projects developed by other organizations.

In this way, it is observed that the Brazilian pulp and paper sector has significant potential to generate carbon credits, promoting climate change mitigation and contributing to the development of a low-carbon economy (Del Rio et al., 2022; Fernando et al., 2021). Despite the commitment of companies in the sector to this agenda, the main challenges of the carbon market in Brazil for pulp and paper companies are related to the accounting of carbon sequestration and institutional and government issues (Da Silveira & De Oliveira, 2021). Key challenges in the carbon market include the absence of specific regulations, the lack of infrastructure and clear criteria for credit commercialization, difficulties in accurately estimating carbon sequestration by forestry projects, the struggle to assign monetary value to forest carbon sequestration, and the complexities of implementing sustainable practices (Da Silveira & De Oliveira, 2021; Munhoz, 2023; Zou & Li, 2019). However, companies are committed to overcoming these obstacles by developing eligible projects, participating in debates about the importance of the regulated market, and disseminating the benefits of GHG sequestration and compensation (Del Rio et al., 2022, IBÁ, 2023). Therefore, the active participation of companies in the carbon market can have a significant impact on climate change mitigation, driving the development of a low-carbon economy in Brazil.

6. FINAL CONSIDERATION

The conducted study allowed for an investigation and identification of low-carbon economy practices aimed at reducing GHG emissions in the operations of the five analyzed pulp and paper companies, as well as their contribution to the Brazilian carbon market. This was achieved through a documentary analysis of their sustainability reports and institutional websites. It was observed that companies in the pulp and paper sector significantly contribute to both direct and indirect emissions of pollutants arising from their production processes; nevertheless, they are actively investing in low-carbon technologies and practices to reverse the existing negative scenario.

It is noteworthy that these low-carbon practices stem from goals aligned with the SDGs. Throughout the study, all actions underscored a strong commitment of these companies to sustainability and corporate responsibility. This work also prompts reflection on the substantial potential of companies in this sector for carbon capture, potentially leading to excellent business opportunities with surplus emissions. This initiative is already being practiced by Companies B and C, who sell their carbon credits in the voluntary market. However, companies like Companies A, D and C are in the early

stages of developing projects for future entry into the carbon market.

However, it was found that companies face challenges in entering the Brazilian carbon market due to the lack of specific regulations for the regulated market that could encourage and facilitate the adoption of sustainable practices in their operations. On the other hand, some companies demonstrate dedication to overcoming limitations by engaging in more projects and debates, reporting their results, and emphasizing the importance of addressing this issue in today's context and its implications for the future.

Moreover, this study brings relevant contributions to both the academic and industrial areas. A detailed analysis of the strategies adopted by the five main pulp and paper companies operating in the Brazilian market was presented, outlining how low-carbon economy practices have been applied in their processes and operations. These practices not only meet the demands of corporate sustainability but also align and contribute to the objectives and guidelines of national environmental policies. Thus, this study enriches both academic and industrial understanding and contributes to policymakers in building a more robust regulatory environment aligned with sustainability goals and greenhouse gas reduction targets. Therefore, with climate change, it is necessary to rethink the way industries produce and operate. Clean and renewable solutions should be prioritized. The carbon market is also important, as it can help to reduce emissions from all companies, with a positive impact on the environment, economy, and society.

Despite the contributions, the study has limitations concerning the sample size and limited access to company data. Hence, it is suggested for future research to explore the theme with a larger number of companies and extended periodicity to examine the temporal evolution of actions outlined in the reports. Furthermore, future studies must focus on the efforts made by companies in other sectors to be more sustainable according to the SDGs, as well as whether they are seeking to enter the carbon market, be it voluntary or regulated.

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