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# Adaptation of Existent Methods for Setting Decarbonization Targets in the Brazilian Power Sector Companies

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**Abstract:** Power sector companies are crucial in global decarbonization, accounting for 32% of global greenhouse gas emissions. Despite frameworks like the Science-Based Targets initiative (SBTi), there is ongoing debate about the adequacy of current target-setting methods and emissions allocation. This paper focuses on Brazil's diverse, renewable-heavy energy mix and complex regulatory environment. It highlights the challenges faced by vertically integrated and predominantly renewable energy companies in meeting SBTi goals, despite their commitment to climate action. The study finds that the current SBTi methodology fails to accurately reflect the efforts of these companies, often penalizing them for emissions beyond their control. An alternative methodology is proposed that excludes unmanageable emissions, aligning targets more closely with operational actions while maintaining transparency in reporting. A key finding is that this new methodology avoids distortions caused by external factors, ensuring emissions reductions are tied to company actions. For renewable power utilities, the methodology emphasizes high-emission categories within the value chain, such as asset construction and maintenance, promoting deeper engagement in decarbonization. A new tool and scenarios were developed, showing that proposed adjustments enhance target accuracy, support global emissions reduction goals, and provide a more transparent and equitable way for companies to report emissions, distinguishing between controllable and external factors.

**Keywords:** decarbonization targets; science-based targets initiative (SBTi); power sector; sectoral decarbonization approach; renewable energy companies; vertically integrated companies

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Academic Editor: Antonio Caggiano

Received: 19 November 2024
Revised: 4 January 2025
Accepted: 6 January 2025
Published: 9 January 2025

**Citation:** Bozelli, H.B.; Guimarães, B.S.; dos Santos, A.A.; Grutzmacher, P.; Botta, C.C.; da Rocha, J.E.N.; Pereira Jr., A.O. Adaptation of Existent Methods for Setting Decarbonization Targets in the Brazilian Power Sector Companies. *Sustainability* **2025**, *17*, 479. https://doi.org/10.3390/su17020479



## 1. Introduction

The power sector companies play a crucial role in the decarbonization process to achieve global warming goals. Over the past decade, the sector has accounted for an average of 43% of global greenhouse gas (GHG) emissions [1]. This high emission rate is because nearly 60% of the world's energy generation comes from natural gas and coal alone [2]. As corporate climate action gains prominence, these companies are under increasing pressure to lead the transition to a low-carbon economy.

The Paris Agreement, established in 2015, guides and encourages power sector companies to reduce their GHG emissions. The agreement aims to limit global warming to below 2 °C, with efforts to restrict it to 1.5 °C above pre-industrial levels. Implementing these goals requires strong commitment and concrete actions, including the transition to cleaner energy sources and technological innovation, enabling the power sector to significantly reduce its dependence on fossil fuels such as natural gas and coal. To meet these ambitious goals, power sector companies need to transform these global guidelines into specific and achievable targets. However, Giesekam et al. [3] found that companies are struggling to translate the Paris Agreement goals into long-term business commitments.

Several methodologies have been developed to help transform goals into concrete and measurable targets, enabling companies, organizations, and governments to align their emissions. These approaches aim to provide clear pathways for emission reductions, considering factors like economic sectors, emission intensity, and available technology. These methodologies can be called Science-Based Targets (SBT) when their GHG emission reduction goals are aligned with state-of-the-art scientific recommendations to limit global warming, such as the studies published by the Intergovernmental Panel on Climate Change (IPCC) [4]. Initiatives like the Science-Based Targets initiative (SBTi) play a key role in ensuring that corporate targets are grounded in scientific evidence, turning the commitments of the Paris Agreement into practical, verifiable actions.

This paper explores the challenges faced by companies in Brazil's power sector when implementing SBTs, with a particular focus on the SBTi's methodological framework for target setting. It specifically addresses the difficulties encountered by vertically integrated power companies in aligning their operations with SBTi requirements, as well as the complexities faced by companies committed to 100% renewable energy generation in pursuing decarbonization targets. Despite their high proportion of renewable assets, these companies often fail to achieve favorable scores under the current SBTi methodology, which does not adequately reflect the efforts of companies already heavily invested in low-carbon energy sources. Additionally, we propose an adaptation of the current power sector guidelines to better account for the unique challenges experienced by companies in Brazil and similar contexts.

Building on this, our proposed adaptation of the SBTi methodology could help other companies worldwide develop robust targets, especially in countries with energy profiles similar to Brazil's, where renewable sources like hydropower are dominant. This methodology aims to more accurately recognize the efforts of companies committed to low-carbon assets, which are often undervalued under the current framework. The ultimate goal is to support the energy sector in achieving net-zero carbon emissions.

This paper is organized as follows: Section 1 presents the Introduction, providing an overview of the study's background, outlining the research hypothesis, and identifying the existing research gap. Section 2 is the Literature Review, with Section 2.1, Background, tracing the historical development of climate goals, with a focus on the evolution of Science-Based Targets (SBTs), and highlights key studies related to decarbonization. Section 2.2, Decarbonization of the Power Sector, examines the current status of the sector and explores strategies for reducing emissions. Section 2.3, Literature Review of Science-Based Targets Methods, reviews existing SBT approaches, identifying their limitations and areas for improvement. Section 3 presents the Materials and Methods, starting with Section 3.1, Identifying the Problem, which discusses the specific challenges faced by companies in Brazil's power sector. Section 3.2, Adapting the SBTi Methodology, outlines proposed adjustments to the SBTi framework, with Section 3.2.1 focusing on Vertically Integrated Power Companies and Section 3.2.2 on Renewable Energy Power Utility Companies. Section 3.3, Modeling Scenarios, describes the scenarios developed to test the proposed methodology, with Sections 3.3.1 and 3.3.2 addressing vertically integrated and renewable energy companies, respectively. Section 4 presents the Results and Discussion, analyzing the findings and how the proposed methodology could facilitate the adoption of SBTs. Finally, Section 5 concludes with a summary of key findings, limitations, and suggestions for future research.

## 2. Literature Review

### 2.1. Background

The 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), held in Paris, marked a turning point in global climate governance. During this event, the Paris Agreement was adopted—an international treaty that established ambitious goals to strengthen the global response to the threat of climate change and enhance countries' resilience to its impacts.

The Paris Agreement aims to reduce GHG emissions within the context of sustainable development. Its central objective is to limit the increase in global average temperature to well below 2 °C above pre-industrial levels, with additional efforts to restrict the rise to 1.5 °C. These targets reflect the scientific consensus on the urgent need to mitigate climate change and avoid irreversible impacts on ecosystems and human populations [5].

To achieve its proposed goals, the Agreement introduced the concept of Nationally Determined Contributions (NDCs), which are the voluntary commitments made by each country to reduce GHG emissions, considering their socioeconomic conditions and local capacities. These commitments are periodically reviewed, allowing progressive adjustments to increase their ambition over time.

In Brazil's case, its NDC sets absolute reduction targets for GHG emissions by 48.4%, or 1.24 $GtCO_{2e}$, compared to 2005 levels by 2025, and an indicative target of 53.1%, or 1.36 $GtCO_{2e}$, by 2030. The country has also committed to achieving climate neutrality, or net-zero emissions, by 2050 [6]. These targets reflect the country's commitment to aligning its economic development with the decarbonization of its economy, fostering technological transitions and advances in climate policies [7].

Monitoring and transparency in the fulfillment of NDCs rely on reliable emissions data, which are collected and organized through emissions inventories. The emissions inventory is a fundamental tool for the formulation and tracking of NDCs, as it provides a detailed analysis of GHG sources and sinks within a specific territory. These inventories allow the identification of priority sectors for emissions reduction and the tracking of progress over time. However, to be effective, inventories must adhere to robust and internationally recognized methodological standards, such as the GHG Protocol [8].

The GHG Protocol is one of the most widely used frameworks for the calculation and reporting of GHG emissions. It provides guidelines that can be applied by governments, businesses, and other organizations, ensuring consistency, transparency, and comparability of data. In the context of NDCs, the GHG Protocol helps standardize accounting methodologies, enabling countries to demonstrate compliance clearly and reliably with their reduction targets. Furthermore, it fosters harmonization between national inventories and corporate efforts to measure and reduce emissions, strengthening the synergy between public policies and private initiatives.

The GHG Protocol categorizes emissions into three distinct scopes, providing a comprehensive view of GHG emission sources. Scope 1 covers direct emissions from sources controlled by the organization, such as industrial processes, fuel combustion in boilers, or company-owned vehicles. Scope 2 includes indirect emissions related to purchased energy, such as electricity, steam, or heat generated by third parties and consumed by the organization. Scope 3 emissions encompass indirect emissions across the entire value chain of an organization and are divided into 15 categories, including those related to purchased goods and services, business travel, product transportation, and the use of sold products. These emissions also include impacts from waste disposal, capital goods production, leased assets, and the end-of-life treatment of sold products. By considering these various categories, companies can identify and mitigate emissions throughout their supply chain and operations, providing a more comprehensive view of their environmental impact.

Category 3 of Scope 3 emissions, which focuses on fuel- and energy-related activities (not included in Scope 1 or Scope 2), refers to emissions arising from the production and transportation of fuels and energy that an organization purchases. These emissions are indirect, as they occur outside the organization's direct operations but are still a result of its energy consumption. Specifically, 3D, which addresses emissions from upstream energy generation and transmission, covers the emissions produced in the process of generating and transmitting the energy that the organization purchases but that are not captured in Scope 1 or Scope 2. This category helps organizations understand the broader environmental impact of their energy consumption by accounting for emissions from energy production and transmission that occur before the energy reaches the organization's facilities or operations. Reducing these emissions often involves working with suppliers to choose cleaner energy sources or improving energy efficiency throughout the supply chain.

The SBTi was established to address the critical challenge of aligning corporate emissions reductions with global climate objectives. It is a collaboration between the Carbon Disclosure Project (CDP), the United Nations Global Compact, the World Resources Institute (WRI), and the World Wide Fund for Nature (WWF). The SBTi provides a standardized framework for developing and validating SBTs in the corporate sector, translating the Paris Agreement's goals into actionable strategies for companies across diverse industries. Its methodology has become the leading global standard for corporate climate action. Additionally, the SBTi has created a sector-specific guide tailored to the unique characteristics and challenges of the power sector, cementing its role in advancing industry-specific climate strategies.

The urgency of transformative climate action was underscored by the IPCC in its Special Report on Global Warming of 1.5 °C, which highlighted the need for rapid and unprecedented societal changes to limit global warming. To maintain a 66% probability of limiting warming to 2 °C, the IPCC sets a maximum cumulative anthropogenic emissions budget of 3670 $GtCO_2$, reduced to 2900 $GtCO_2$ when accounting for other greenhouse gases. By 2011, approximately 1890 $GtCO_2$ had already been emitted, leaving only 1010 $GtCO_2$ available from that point onward.

The IPCC's Fifth Assessment Report (AR5) defined four Representative Concentration Pathways (RCPs), corresponding to approximate radiative forcings of 2.6 $W/m^2$, 4.5 $W/m^2$, 6 $W/m^2$, and 8.5 $W/m^2$. These RCPs, spanning 1850–2100, represent different climate policy scenarios. Among them, RCP 2.6 is the most ambitious, aiming to stabilize greenhouse gas concentrations below 450 ppm $CO_{2e}$. This pathway requires cumulative emissions of 990 $GtCO_2$ by 2100 and aligns with the goal of limiting warming to 2 °C. Achieving this scenario necessitates drastic emission reductions, reaching net-zero emissions in the second half of the century, supported by advanced technologies such as carbon capture and storage (CCS) to offset residual emissions.

In response, the SBTi has introduced technical resources to help companies establish GHG reduction targets aligned with a 1.5 °C warming threshold. For the power sector, the SBTi has endorsed specific 1.5 °C-aligned pathways, providing clear guidance for setting emissions reduction targets that demonstrate climate leadership. The SBTi primarily draws scenarios from the Integrated Assessment Modeling Consortium (IAMC), which compiles over 400 peer-reviewed emission trajectories evaluated in the IPCC Special Report on Global Warming of 1.5 °C (SR15). These scenarios must meet stringent criteria, ensuring they are plausible, consistent, and aligned with global climate goals.

In the initial classification, scenarios are assessed using temperature limits and probabilities based on the reduced-complexity climate model MAGICC6, adopted by the IPCC in SR15 [5]. This evaluation considers projected warming by 2100 and prior warming peaks. Scenarios aligned with the Paris Agreement aim to keep warming "well below 2 °C" (66% probability) or limit the increase to 1.5 °C (50% probability), including trajectories with little or no overshoot. Scenarios failing to meet the Paris Agreement's urgency, such as those projecting emission peaks before 2020 or after 2025, are excluded. These pathways also exclude those relying excessively on speculative $CO_2$ removal (CDR) technologies due to their associated risks and uncertainties. This refinement process narrows an initial set of 177 scenarios to 20 that are consistent with the 1.5 °C target. These trajectories serve as a foundation for SBTi methodologies, such as the Absolute Contraction and Sectoral Decarbonization Approach, providing robust pathways for corporate climate action.

### *2.2. Decarbonization of the Power Sector*

The deep decarbonization of the power sector is a cornerstone of all climate scenarios that limit global warming to 1.5 °C. Achieving these scenarios requires sector emissions to decrease by 70–92% between 2020 and 2035 and to approach net zero by 2040–2045. This sharp reduction is driven by rapid cost declines in solar, wind, and energy storage technologies [9], supported by favorable policy frameworks and increasing demand for renewable energy [9]. The share of electricity in final energy consumption is also projected to rise steadily through 2050, further underscoring the power sector's critical role in global decarbonization efforts. Accordingly, SBTi pathways aligned with the 1.5 °C mandate significant near-term emission reductions (2020–2035) and the achievement of near net-zero emissions by 2040.

Currently, the SBTi recommends two methods for setting Scope 1 and 2 emission targets. The first one is the Absolute Contraction Approach (ACA), which requires all companies to reduce their absolute emissions by the same proportion. This target is expressed in terms of total metric tons of $CO_2$ equivalent ($tCO_{2e}$), ensuring a standardized approach to measuring and reducing greenhouse gas emissions. Under this framework, all companies, regardless of their sector, are required to achieve the same percentage reduction in emissions. In the medium term, companies are expected to reduce their emissions by 4.2% annually, which equates to a 42% reduction over a decade. In the long term, the target is even more ambitious, requiring a 90% reduction in emissions. This approach aims to drive substantial and consistent progress toward global decarbonization goals across all industries.

The second one is the Sectoral Decarbonization Approach (SDA), a method designed to guide companies in setting science-based emissions intensity reduction targets [10]. The SDA method aligns corporate carbon intensity pathways with sector-specific decarbonization scenarios derived from global climate mitigation strategies. The SDA allows companies to set targets that account for both projected activity growth and initial carbon performance.

A sector-specific target for the energy sector is expressed in terms of metric tons of $CO_2$ equivalent per megawatt-hour ($tCO_{2e}/MWh$), reflecting the unique characteristics and requirements of the sector. Unlike absolute targets that apply uniformly across all industries, the percentage reduction in emissions varies between companies within a sector, depending on their starting points and expected growth rates. In the medium term, companies are expected to achieve significant emissions reductions, ranging from 70% to 92%. Looking ahead to the long term, the goal is to reach a near-zero emissions intensity of 0.0092 $tCO_{2e}/MWh$. This tailored approach aims to align the energy sector with broader global climate goals while accounting for the sector's specific operational realities.

Although the ACA was previously applicable to targets aligned with 2 °C, companies must now set targets compatible with a well-below 2 °C scenario or the more ambitious 1.5 °C scenario. ACA is broadly applicable, while SDA is used for certain "homogeneous" sectors and currently only calculates targets aligned with 1.5 °C for the energy sector. For certain sectors, the SBTi allows or requires the use of specific methods for target setting, including some variants of ACA and SDA (e.g., for aviation) and other distinct methods (e.g., for financial institutions). Dedicated methods and guidelines for other sectors are still under development.

For Scope 3 emissions, the SBTi's requirements are less stringent, acknowledging that companies have less ability to quantify and influence these emissions. Companies must set science-based targets for Scope 3 if these emissions represent at least 40% of the total Scope 1, 2, and 3 emissions, and the targets must cover at least two-thirds of Scope 3 emissions. Companies can use methods other than ACA and SDA, with Scope 3 targets still aligned with a 2 °C scenario, as well as the well-below 2 °C or 1.5 °C scenarios. Alternatively, companies may set supplier or customer engagement targets to encourage them to set their science-based targets for their Scope 1 and 2 emissions.

For Scope 2, SBTi also allows for setting targets to increase the procurement of renewable electricity, and Scope 3 engagement targets involve directing a percentage of suppliers and customers (based on Scope 3 emissions or procurement spend) to adopt science-based targets.

### *2.3. Literature Review of Science-Based Targets Methods*

The literature points out various limitations and challenges in implementing SBTs. While the adoption of SBTs is voluntary and should not replace more ambitious climate policies, it remains unclear whether they help or hinder the adoption of the policies necessary to align with the Paris Agreement.

Bjørn [11] identifies a problem with how renewable energy certificates (RECs) are used by companies to report Scope 2 emission reductions as part of their SBT efforts. While current emission accounting standards allow companies to use RECs for progress on purchased electricity emissions reductions, previous analyses suggest that this practice may not lead to additional renewable energy production. This could result in an overestimation of mitigation effectiveness, as Scope 2 emission trajectories from 2015 to 2019, when excluding REC benefits, are not aligned with the 1.5 °C target and barely meet the Paris Agreement's "well below 2 °C" goal [12].

Walenta [13] explores the potential of corporate climate action tools like risk assessments and SBTs but raises concerns about their effectiveness and potential manipulation. SBT adoption, while promising, raises doubts about its ability to stabilize the climate, especially given disparities in wealth accumulation and emission reduction burdens. Faria and Labutong [14] highlighted issues with the SBT's use of "grandfathering", which allocates emission quotas based on historical data, potentially perpetuating global inequalities. Additionally, emission reduction trajectories often assume continuous growth in energy and materials, with heavy reliance on large-scale carbon removal, overlooking alternative scenarios with more sustainable futures and less environmental impact [12].

Various methods exist for establishing science-based targets, allowing companies to adapt their strategies to sector-specific and operational conditions. These methods range from linear emission reduction approaches to more complex tools considering carbon intensity per unit of production or sector alignment. Faria and Labutong [14] describe four such methods, emphasizing the importance of aligning corporate actions with climate science to meet global temperature goals. However, they note that all methods incorporate historical emissions as a basis for future budgets, favoring countries and companies with higher accumulated emissions, creating inequality in the distribution of required reductions. Bjørn et al. [15] analyzed seven SBT definition methods and found significant variations in emission allocation principles, corporate variables, and global scenarios. The study highlighted frequent imbalances between corporate targets and global emission allowances, influenced by factors like geography, economic sector, and company growth rates, stressing the need for context-specific methods to ensure alignment with global climate goals.

The application of SBT methodologies reflects significant inequalities between wealthy and poorer countries, showing a gap in the global integration of science-based targets. Studies reveal that SBT adoption is still limited in low- and middle-income countries, emission-intensive sectors, and small- and medium-sized enterprises, while large corporations in developed regions, like Europe, dominate the adoption of targets. In 2021, European companies accounted for over half of the approved SBTs, with the majority of the remaining share coming from North American and Asian companies. Meanwhile, Latin America, Africa, and Oceania combined for less than 6% [11]. This disparity is linked not only to a lack of resources and infrastructure but also to a disconnect between corporate targets and national climate contributions.

While SBTi focuses on emissions reduction, it may not fully address the broader sustainability goals, including social equity and economic stability, which are crucial for the power sector's sustainable development. Immink et al. [16] point out that SBTi methodologies fail to adequately consider equity principles and common but differentiated responsibilities, burdening companies in more vulnerable contexts, while others contribute insufficiently to global emission mitigation. This inequitable approach undermines the universality of targets and may perpetuate existing inequalities. It is clear that the Global South, where the adoption of science-based targets is still limited, faces specific challenges such as insufficient infrastructure, lack of access to adequate financing, and weaker regulatory and market pressures for sustainable practices. Additionally, many Latin American companies, particularly small and medium-sized ones, have limited resources to invest in robust emission mitigation strategies or cover the costs associated with certification and target validation. These factors highlight the need for a more detailed regional analysis, identifying key barriers and opportunities for increasing SBT adoption in Latin America.

Despite various criticisms of the SBTi, Maia and Garcia [17] identified benefits of adopting SBTs by energy sector companies. Companies that adopt targets perform significantly better in terms of emission reductions and transition to renewable energy, although the adoption of SBTi may be more a reflection of geographical and marketing contexts than a direct cause of emission reductions.

Studies such as those by Giesekam et al. [3] show significant progress in implementing Scope 1 and 2 SBTs, while Scope 3 remains challenging due to lower control over these emissions. The SBTi reported a 25% reduction in Scope 1 and 2 emissions between 2015 and 2019, exceeding the requirements for a 1.5 °C scenario.

The SDA methodology, developed by Krabbe et al. [10], was created to translate global GHG reduction targets into the corporate level, aligning them with the carbon budgets needed to limit global warming to 2 °C. Based on global mitigation scenarios such as the 2DS from the International Energy Agency (IEA) [18], the SDA defines carbon intensity pathways specific to each sector, considering activity projections and the initial performance of companies. The method aims to ensure that corporate emissions remain within sectoral limits while promoting the gradual convergence of companies' carbon intensities to the sectoral average by 2050.

The SDA presents significant innovations by integrating sector-specific characteristics, such as costs and mitigation potentials, and by considering the projected growth of business activities. One of the pillars of the methodology is ensuring that total emissions targets for all companies within a sector do not exceed the sectoral carbon budget. Additionally, the methodology considers the current performance of companies, allowing for a fair and gradual transition toward global climate goals.

The methodological section of the SDA describes how sectoral emissions pathways are translated into company-specific intensity pathways. The process uses physical indicators (such as tons of steel produced) or monetary indicators (such as value added) to relate emissions to activity levels. This approach is particularly effective for sectors with uniform products or activities, as it allows for a more accurate correlation between emissions and business operations [10].

While the SDA is widely applicable and innovative, it has gaps that limit its effectiveness in certain contexts. For example, the methodology does not differentiate between manageable and non-manageable emissions, which may lead to distortions in regulated or predominantly renewable markets. Additionally, the focus on carbon intensity targets for homogeneous sectors may be inadequate for companies that already operate with renewable sources or those facing temporary high emissions during the expansion of new assets. These challenges highlight the need for methodological adaptations to increase the effectiveness and representativeness of the SDA in specific contexts.

## 3. Materials and Methods

### 3.1. Identifying the Problem

Brazil was chosen as a case study for several compelling reasons. Contrary to the notion that Brazil struggles to meet international standards, the country's energy mix is already more aligned with renewable energy than many global benchmarks. Brazil's energy sector is notably diverse, with a strong presence of renewable energy sources, particularly hydropower, far exceeding the global average [19]. In 2022, Brazil's electricity matrix was dominated by hydropower, accounting for 63.1% of generation, complemented by other sources contributing 36.9%. Among these, wind energy represented 12.1%, natural gas thermal plants 6.2%, and biomass 7.6% [19]. Renewable sources made up 87.9% of the matrix, a significant figure more than three times the global average and nearly three times the OECD countries' average [20]. Conversely, off-grid systems showed a different profile, with 96% of electricity generated from diesel and fuel oil, while natural gas (2.2%), biomass (1.1%), and hydropower (0.7%) played minor roles [21].

This composition resulted in total emissions of 44.3 Mt $CO_2$ in 2022, divided as follows: 21.6 Mt $CO_2$ from the National Interconnected System (SIN), 20.3 Mt $CO_2$ from self-generation, and 2.5 Mt $CO_2$ from off-grid systems. In terms of efficiency, Brazil achieved 62 $kgCO_2$/MWh, a figure 91% lower than China's, 83% below the United States, and 75% lower than OECD countries in Europe [19].

By 2030, Brazil's NDC commitments aim to achieve a 66% share of hydropower in electricity generation; 23% of renewable energy (excluding hydropower) in electricity supply; a 10% improvement in energy efficiency in the electricity sector; an 18% share of sustainable bioenergy in the energy matrix; an increase in renewable sources (excluding hydropower) from 28% to 33%; and a 45% share of renewables in the overall energy mix [22].

However, the existing SBTi framework tends to favor countries with a higher reliance on fossil fuels, which can complicate the alignment of Brazil's highly renewable profile with SBTi's requirements. The current criteria, centered on stationary combustion or absolute contraction of Scope 1 and 2 [23], fail to address the core challenge of a renewable generator, which, as shown by the companies' inventory analysis, has emissions associated with the construction process, specifically emissions in Scope 1 and 2 of a GHG inventory. Therefore, a new target proposal is necessary, as the current SDA energy target—based on an indicator that divides stationary combustion ($tCO_{2e}$) by total generation (MWh)—does not apply to

100% renewable generators, which would likely have targets below the sectoral Net Zero set for 2040.

To address this challenge, the SBTi recommended that companies in this situation set ACA targets. However, this approach is also less suitable for expanding renewable generators, as the construction of new assets tends to increase absolute emissions, due to factors such as vegetation removal, higher fuel use, and, primarily, large emissions associated with the acquisition of goods and services. The SDA is focused on companies seeking to decarbonize their electricity mix, which does not apply to companies that already use 100% renewable sources. Additionally, the Absolute Contraction method imposes emission reduction targets that hinder the expansion of renewable generation, which is critical for companies investing in new sources, as the construction of new projects generates carbon emissions.

The second challenge relates to the fact that Brazil's power sector is highly regulated, with the state centralizing control over the country's generation supply [24] and many vertically integrated companies operating under the dispatches of the National Interconnected System (SIN).

In Brazil, the large groups are considered verticalized as they have generation, transmission, and distribution (T&D) and commercialization, even if they are legally separate entities (under different National Registry of Legal Entities, Cadastro Nacional da Pessoa Jurídica in Portuguese). The original SBTi target for verticalized groups presents challenges for the country's companies due to its unique operation structure. Even when fully reliant on renewable energy assets, these companies must account for high-emission factors in their inventories. This is mainly because electricity dispatch is controlled by national authorities such as the National System Operator (ONS) and the Brazilian National Electric Energy Agency (ANEEL), which influences the overall carbon footprint of these companies.

In the regulated Brazilian market, energy is procured through regulated auctions, requiring distributors to source both fossil and renewable energy. In practice, only 10% of the energy purchased for resale by distributors serving the captive and regulated market can be acquired bilaterally, with some discretion over the energy source [25]. The emissions are calculated based on the grid Emission Factor (EF) provided by the Ministry of Science, Technology, and Innovation (MCTI). The first challenge identified is the inability to manage emissions from Scope 3 Category 3, related to the energy generation purchased and sold to the final consumer. Additionally, companies have no control over reducing fossil-based generation, as this is determined by Brazil's government. Although the Brazilian energy mix presents an average of emissions lower than the world's, according to the parameters of the SBTi model, the outlook is for a more challenging future scenario. The expected increase in the installed capacity of fossil sources until 2031 will increase the EF of the national electrical system from 0.031 in 2024 to 0.056 Mt. $CO_{2e}$/TWh [24], consequently intensifying the emissions of Brazilian companies. With an increasingly carbonized grid, companies will have difficulty reducing their emissions and achieving the goals established by the SBTi, requiring the adoption of even more robust strategies to decarbonize their operations. This highly renewable and regulated context offers valuable insights into the challenges faced by countries that are already renewable leaders when it comes to implementing the SBTi methodologies.

Companies are required to follow the method established by the SBTi to determine their progress in reducing emissions. Based on the analysis of several factors, such as fuel combustion, electricity consumption, and sales, companies will be assessed using these equations. The results of this evaluation are used to assign a score that reflects the company's performance relative to their decarbonization target.

Equations (1) and (2) represent the current guidelines of the SDA, which provide two methods of calculating Target 1—a mandatory method and an alternative method. Target 1 refers to the carbon intensity of a company's electricity sales, specifically measuring the emissions per unit of electricity sold (measured in MWh). The company's progress toward reducing emissions is assessed by comparing this carbon intensity to the set decarbonization targets.

$$\text{Target 1 (mandatory)} = \frac{[\text{Fuel combustion} + \text{electricity purchased(S3C3)}]\ \text{tCO}_{2e}}{[\text{Total electricity sold (generated} + \text{purchased)}]\ \text{MWh}}, \quad (1)$$

$$\text{Target 1 (alternative)} = \frac{[\text{Scope1} + \text{Scope electricity purchased(S3C3)}]\ \text{tCO}_{2e}}{[\text{Totalel ectricity sold (generated} + \text{purchased)}]\ \text{MWh}}, \quad (2)$$

In theory, the two methods provide flexibility depending on the company's emission sources and reporting structure, allowing companies to select the method that best aligns with their operational context while still achieving the same decarbonization goals. However, neither method is entirely adequate for highly renewable power companies.

Table 1 analyzes three distinct types of companies in the power sector: fossil-based, renewable, and verticalized. It provides a detailed breakdown of the SBTi equations and their application while illustrating how these equations fail to adequately address the challenges faced by renewable and verticalized companies. Fossil-fuel-based companies may achieve very low or even null SDA scores, as their emissions align more closely with the current targets. Renewable energy companies, however, often receive disproportionately high SDA values, which do not accurately reflect their operational emissions. Verticalized companies typically fall in the medium SDA range, with their results heavily influenced by dispatch decisions made by the National System Operator (ONS), which affects their overall carbon footprint.

**Table 1.** Breakdown of Equation Terms and Impact on the Sectoral Decarbonization Approach (SDA).

| Equation Composition | Equation Terms | Fossil Generation | Renewable Generation | Verticalized Brazilian |
|---|---|---|---|---|
| Numerator ($tCO_{2e}$) | Fuel combustion (Scope 1) | Very high | Minimum or null | Variable |
| | Electricity purchased (Cat 3 Scope 3) | Minimum or null | Minimum or null | Very high and unmanageable |
| Denominator (MWh) | Total MWh | Average | High | Very high |
| Trends | SDA characteristic | Very high SDA | Very low or null SDA | Average SDA |

### *3.2. Adapting the SBTI Methodology*

#### 3.2.1. Vertically Integrated Power Companies (Including T&D Activities)

With these challenges in mind, we then evaluated how the existing equation used in the SDA could be modified to better reflect the realities faced by these vertically integrated companies. To address the management problems for vertically integrated companies, we proposed alterations for Scope 3 Category 3D (here called S3C3D), related to the "Generation of purchased electricity that is sold to end users" [8]. The suggestion involves splitting this category into 3D1 and 3D2, with the former referring to the non-manageable contractual portion of purchased energy for resale and the latter to the manageable portion.

Scope 3D1 emissions, resulting from the non-manageable generation of energy bought and sold to end consumers, would be classified as non-manageable. This classification includes emissions from regulated auction contracts and other non-manageable contracts, such as the nuclear energy quota, structured hydroelectric plants, and the Alternative

Sources Incentive Program—PROINFA. On the other hand, Scope 3D2 emissions stem from the manageable generation of energy bought and sold to end consumers, including emissions from regulated bilateral contracts (CBR, up to 10%) and bilateral contracts in the free energy market (trading companies).

The study recommends transitioning from the current S3C3D category to a refined S3C3D2 classification—allowing companies to focus on manageable emissions—it also emphasizes the importance of maintaining the reporting of S3C3D1 emissions. This ensures that the full scope of emissions, including those outside direct corporate control, are accounted for.

Equations (3) and (4) represent our proposed calculations for vertically integrated power companies, including both the mandatory and alternative methods of calculation.

$$\text{Target 1 (mandatory)} = \frac{[\text{Fuel combustion} + \text{electricity purchased (S3C3}\mathbf{D2}\text{)] tCO}_{2e}}{[\text{Total electricity sold (generated} + \text{purchased}\mathbf{D2}\text{)] MWh}}, \tag{3}$$

$$\text{Target 1 (alternative)} = \frac{[\text{Scope 1} + \text{Scope electricity purchased (S3C3}\mathbf{D2}\text{)] tCO}_{2e}}{[\text{Total electricity sold (generated} + \text{purchased } \mathbf{D2}\text{)] MWh}}' \tag{4}$$

Aligned with SBTi's current analysis, which is focused on fossil fuel emissions, the recommendation is that the emissions from bilaterally purchased energy should also be quantified by fossil fuels, i.e., related to the fuel burned in these plants. So, in the case of renewable generation, the emission is zero.

#### 3.2.2. Renewable Energy Power Utility Companies

Regarding the target for renewable electricity generating companies, our goal was to formulate a target that considers emissions from the entire supply chain, including those from the construction process.

For Scopes 1 and 2, our methodology involves setting an absolute target. The operational boundary encompasses 95% of Scopes 1 and 2 emissions and 67% of Scope 3 emissions. Our ambition includes a short-term reduction of 4.2% per year and a long-term goal of a 90% reduction.

Regarding Scope 3 targets, our analysis reveals that the primary challenge for the renewable sector lies within the value chain, particularly during the commissioning years. Absolute contraction limits the potential for new developments, necessitating the adoption of an intensity target. Equations (5) and (6) in this study represent our proposed calculations for companies engaged in 100% renewable energy generation, encompassing both mandatory and alternative methods of calculation.

$$\text{Scope 3 target (mandatory)} = \frac{[Service\ Goods + Capital\ Goods\ ]\ tCO_{2e}}{[Installed\ electricity\ generating\ capacity]\ MW}' \tag{5}$$

$$\text{Scope 3 target (alternat.)} = \frac{[Scope\ 1 + Scope\ 2 + [Service\ Goods + Capital\ Goods]]\ tCO_{2e}}{[Installed\ electricity\ generating\ capacity]\ MW} \tag{6}$$

Decarbonizing the renewable power sector is intrinsically tied to the decarbonization of related construction sectors. To address this, we developed a method to map a decarbonization pathway based on the life-cycle emission intensity of key inputs such as steel, cement, chemicals, and electricity—materials already included in SBTi's Sectoral Decarbonization Approaches. The overarching goal is to define the emission factor for each renewable energy project based on its life-cycle emissions.

### *3.3. Modeling Scenarios*

Our method is structured into four main steps. The first step involves quantifying emissions for each selected power source based on its life-cycle emission intensity. We focused on primary renewable energy sources that have experienced significant market growth in recent years, including hydropower, solar, and onshore wind. For this analysis, we utilized datasets from Ecoinvent 3.9.1, which provide detailed emission data for each energy source by evaluating the emissions of its components. Each component's emissions were further broken down and quantified based on the materials used in its production. Due to the wide range of materials involved, they were grouped into specific categories, such as steel, cement, chemicals, and others, to simplify the analysis.

In the second step, we calculated a unique Emission Intensity Factor ($tCO_{2e}/MWh$) for each energy source. This factor considers both the total life-cycle emissions and the proportion of emissions attributed to specific emitting components. The Emission Intensity Factor is determined by combining the Infrastructure Required (t/MWh) for each material with its respective Emission Factor ($tCO_{2e}/t$). For hydroelectric plants, methane emissions from reservoirs were excluded from the calculation to focus exclusively on infrastructure-related emissions.

In the third step, the goal was to define the Future Emission Intensity Factor for each material. This was achieved by applying reduction targets to each material group that constitutes the infrastructure—specifically chemicals, steel and iron, cement, and electricity used during the construction process. These targets were aligned with critical milestones for 2020, 2035, 2040, and 2050. The temporal decarbonization of each material was calculated using consolidated decarbonization trajectories set by the SBTi for sectors such as steel and iron [26], electricity [27], and cement [28]. For chemicals, temporal decarbonization percentages were derived from IEA scenarios and other peer-reviewed scientific literature [2].

Finally, in the fourth step, we cross-referenced the projected emission reductions for infrastructure materials with the anticipated growth trajectories of each renewable energy source. The goal was to define Future Emission Factors for each generation source in each timestep of the milestones. With these steps, it was possible to establish a specific decarbonization pathway for each energy source, grounded in the progressive decarbonization of the materials used in its construction. This step provides a comprehensive understanding of how sectoral expansion interacts with supply chain decarbonization, enabling the development of realistic and scalable pathways for achieving climate targets.

The following methodological step involved validating the effectiveness of the developed method through the application of two distinct case studies. These case studies were designed to evaluate the practical implementation and accuracy of each proposed modification within the decarbonization pathway framework. By applying the method to scenarios built to represent real-world applications of the methodology, it was possible to analyze its robustness, adaptability, and potential to generate reliable emission reduction trajectories.

#### 3.3.1. Vertically Integrated Power Companies

To validate the methodology for vertically integrated companies, it was applied to three distinct business cases, each designed to represent different scenarios within the power sector. The first case represents the expected decarbonization pathway for the power sector as a whole, with data sourced from the World Energy Outlook 2019 [29]. This case serves as a benchmark, illustrating the projected trajectory under current policies, technologies, and market dynamics. It provides a reference point against which the performance of individual companies can be assessed.

The second case, referred to as Company A, models a vertically integrated Brazilian power sector company. The parameters for this case were derived from a real company operating within the Brazilian market, with adaptations made to preserve confidentiality. Company A is characterized by an emission factor below the sectoral average, reflecting a low-emission business model. This case highlights the potential for companies to outperform the sector in terms of emission intensity and demonstrates the feasibility of aligning business practices with ambitious decarbonization goals.

In contrast, a third case was designed to model a hypothetical company, referred to as Company B. This company operates with the same energy output (MWh) as Company A but exhibits emissions higher than the sectoral average of 0.380 $tCO_2$/MWh. Company B represents a high-emission scenario, providing a counterpoint to Company A. This hypothetical case was developed to highlight the differing challenges faced by companies with varying emission intensities.

By analyzing these three cases, the study explores a range of companies' characteristics within the power sector, offering insights into the effectiveness of the proposed methodology across diverse operational profiles. Table 2 provides a detailed description of each case, including key parameters such as emission intensity factors and activity output for the base year enabling a comprehensive comparison and validation of the methodology.

**Table 2.** Manageable Cases.

| Scenario Characteristics | Company A | Company B |
|---|---|---|
| Base year \| Activity output (MWh) | 6,236,235 | 6,236,235 |
| Base year (2021) \| Generation related emissions ($tCO_{2e}$) | 346,533 | 2,839,791 |
| Base year (2021) \| Emission Intensity Factor ($tCO_{2e}$/MWh) | 0.056 | 0.455 |

### 3.3.2. Renewable Energy Power Utility Companies

To model renewable energy power utility companies, a methodology similar to that used for vertically integrated companies was employed. Three distinct cases were developed to capture a range of operational and emissions scenarios, reflecting both current market conditions and potential variations in emission intensities.

The first case, referred to as Company A, is based on the sector's traditional emission and performance projections, sourced from the Ecoinvent 3.9.1 database. This case represents a baseline scenario, offering a comprehensive view of emissions associated with renewable energy companies operating at an average sectoral performance level. The data derived from Ecoinvent provides a robust foundation for establishing industry benchmarks and for comparison with alternative scenarios. Evaluating the values found in the Ecoinvent database (Company A), it is observed that solar energy currently has the highest emission intensity in its life cycle, followed by hydro and wind energy.

In addition to Company A, two hypothetical cases were created to represent companies operating at opposite ends of the emissions spectrum. Company B models a renewable energy company with a $tCO_{2e}$/MWh ratio significantly lower than the sector average, demonstrating a highly efficient and low-emission operation. This scenario highlights the potential for renewable energy companies to achieve emissions performance that surpasses current industry standards, serving as an aspirational model for the sector. Conversely, Company C represents a renewable energy company with a $tCO_{2e}$/MWh ratio considerably higher than the sector average. This case simulates a high-emission scenario, showcasing the challenges and opportunities for companies that lag in emissions performance. It emphasizes the necessity of targeted interventions and tailored strategies to bring high-emission companies in line with sectoral decarbonization goals.

The methodology was applied to model renewable energy companies for the year 2040. This application allows for the projection of future emissions scenarios and enables the identification of the most effective pathways for decarbonization within the renewable energy sector over the next two decades.

Together, these three cases provide a comprehensive framework for assessing the applicability and robustness of the methodology for renewable energy power utilities and different generation sources. This comparative analysis ensures that the methodology is versatile and effective across varying operational profiles, emissions, and generation sources within the renewable energy sector. Table 3 presents a detailed description of each case, including key parameters such as emission intensity, energy output, and underlying assumptions. This comparative analysis ensures that the methodology is versatile and effective across varying operational profiles, emissions, and generation sources within the renewable energy sector.

**Table 3.** Ecoinvent emission factors ($tCO_{2e}/MW$) derived from the Ecoinvent database for each analyzed generation source and company.

| Generation Source | Company A | Company B | Company C |
|---|---|---|---|
| Hydroelectric | 1814 | 1400 | 2000 |
| Solar photovoltaic | 2588 | 500 | 3000 |
| Wind | 593 | 500 | 800 |

## 4. Results and Discussion

The modelling results for vertically integrated companies (Figure 1 and Table 4) demonstrate convergence towards a net-zero emission intensity of 0.009 $tCO_{2e}/MWh$ by 2040, aligning with science-based target expectations. Both companies demonstrate comparable percentage reductions in both absolute emissions (around 71.7–72.4%) and emission intensity (around 75.7–76.4%) relative to their baselines. This suggests that while Company B's absolute emissions and intensity are much higher, they are making comparable efforts in terms of percentage reduction aligned with SBTs.

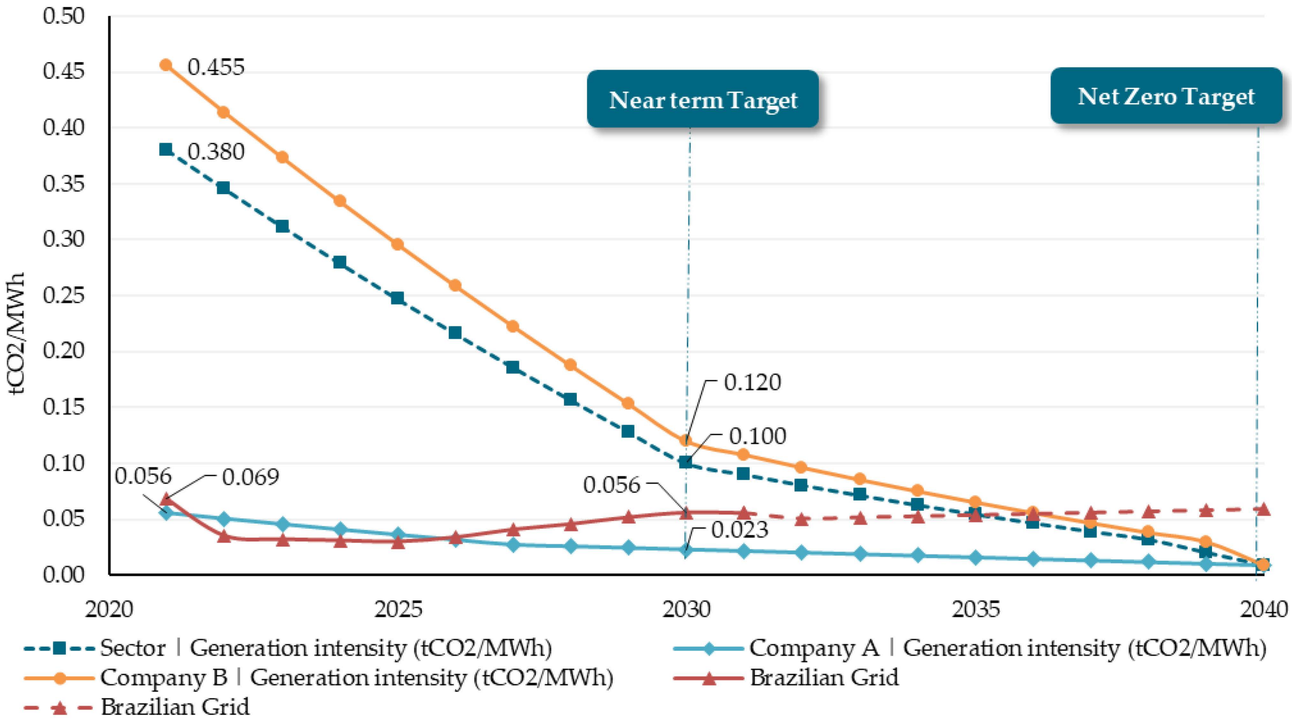


**Figure 1.** Decarbonization pathway for vertically integrated companies.

Figure 1 compares the emission intensity curves of the power sector (based on IEA projections), Company A, Company B, and the Brazilian grid. The Brazilian grid's curve uses EPE data (2020–2031) and a linear projection to 2040, and it reveals that its current trajectory, despite high renewable penetration, points to a rising emission factor for the Brazilian power sector, underscoring the necessity of decarbonization initiatives, a challenge that the methodology appears well-suited to address and potentially mitigate. This highlights the need for reassessing emission reduction strategies in contexts with already substantial renewable energy integration. Notably, Company A and B's data reflect only manageable emissions. The analysis also shows that companies with emission intensities both above (Company B) and below (Company A) the sector average can achieve their targets, demonstrating the methodology's robustness and adaptability.

**Table 4.** Decarbonization pathway for vertically integrated companies.

| Scenario Characteristics | Company A | Company B |
|---|---|---|
| Target year (2031) ∣ Generation-related emissions ($tCO_{2e}$) | 98,000 | 782,671 |
| Target year (2031) ∣ Emission Intensity Factor ($tCO_{2e}$/MWh) | 0.023 | 0.120 |
| % SBT reduction ∣ Generation-related emissions ($tCO_{2e}$) | 71.7% | 72.4% |
| % SBT reduction ∣ Emission Intensity Factor ($tCO_{2e}$/MWh) | 75.7% | 76.4% |

In all scenarios analyzed, emissions showed a more pronounced reduction from 2021 to 2030. This reflects the incorporation of the science-based target premises in the developed methodology, driving companies to adopt more stringent mitigation measures during this critical period. This suggests that companies may need to adopt more aggressive ambitions before 2030, as achieving the short-term target is crucial. Once the 2030 target is met, the subsequent ambition leading up to 2040 may not need to be as drastic. However, this outcome depends on the current emissions intensity of the companies. The higher the emissions intensity, the more critical it becomes for these companies to make significant strides by 2030. Consequently, for companies with greater emissions intensity, the period leading up to 2030 will require more intense efforts to ensure that the transition to the 2040 target is smoother and less demanding.

For renewable energy companies (Table 5 and Figure 2), the results also align with SBTi methodologies, showing convergence towards net zero by 2050, consistent with SBTi's emission reduction projections. This analysis confirms that even companies with above-average emissions within the renewable energy sector can achieve the proposed targets, highlighting the methodology's effectiveness in this context. The renewable energy sector's net-zero emissions target is set for 2050, in line with the SBTi benchmarks of the sectors that make up the supply chain used in the calculations.

The summary of key reductions demonstrates the substantial effort required to achieve the near-term and long-term emission reduction targets for renewable energy companies. Between 2020 and 2030, emissions across all generation sources (solar, hydro, and wind) are expected to decrease by approximately 30% for all companies, marking a significant reduction within the next decade.

**Table 5.** Emission factors of the power plants ($tCO_{2e}$/MW) according to the generation source.

| Generation Source | Scenario | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Solar | Company A | 2589 | 1856 | 851 | 114 |
| | Company B | 500 | 358 | 232 | 114 |
| | Company C | 3000 | 2151 | 986 | 114 |
| Hydro | Company A | 1815 | 1264 | 608 | 100 |
| | Company B | 1400 | 975 | 469 | 100 |
| | Company C | 2000 | 1393 | 670 | 100 |
| Wind | Company A | 593 | 413 | 188 | 28 |
| | Company B | 500 | 348 | 159 | 28 |
| | Company C | 800 | 557 | 254 | 28 |

To achieve Near-term Targets and Net Zero (NZ) Targets, companies will need to significantly reduce their emissions over the decades. For the base case, Company A, the life-cycle emissions of new solar energy plants must decrease by 95.6% between 2020 and 2050, hydro by 94.5%, and wind by 95.3%. This reduction can be less demanding for companies that already have a low level of emissions in their life cycle and even more challenging for companies with high emission levels. The emission reductions observed in the analysis align closely with the expected targets set by SBTs.

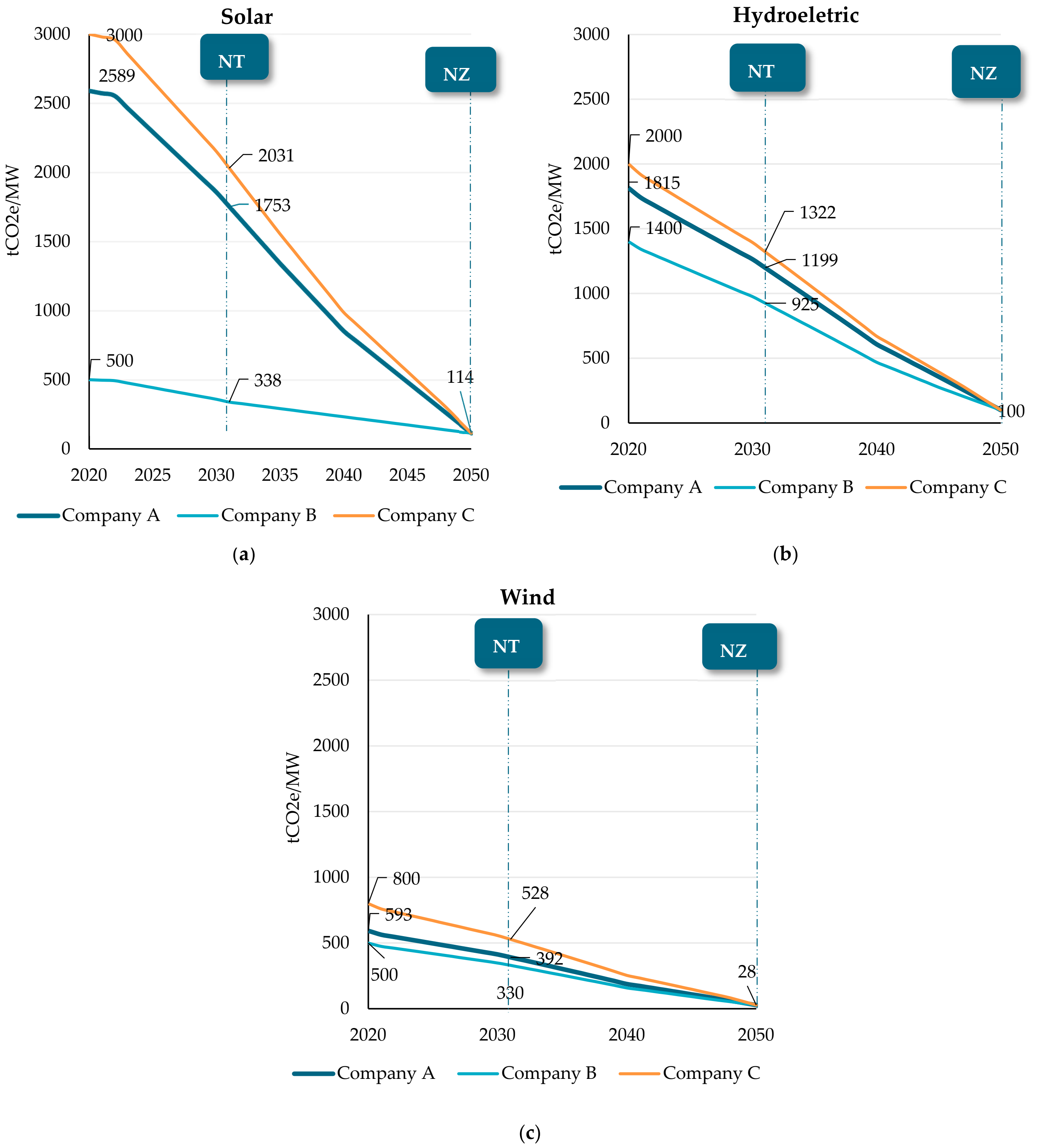


**Figure 2.** Decarbonization pathway for renewable companies according to the generation source.: (**a**) solar; (**b**) hydroelectric and (**c**) wind. NT refers to Near-term Target, and NZ refers to Net Zero Target.

## 5. Conclusions

The study reveals that despite significant efforts to align with the climate agenda, vertically integrated and predominantly renewable energy companies face substantial challenges in adhering to SBTi targets. It highlights that while Brazilian companies recognize the importance of science-based targets, the current framework offers limited flexibility for effective implementation. The study underscores the need for adaptive approaches to address the sector's unique characteristics and proposes an alternative methodology that more accurately reflects these companies' efforts to achieve decarbonization goals.

- Enhancing Flexibility in the SBTi Framework: The current SBTi framework needs to be more adaptable to address the unique challenges faced by vertically integrated companies and those with a high share of renewable energy. Introducing sector-specific guidelines would enable companies to tackle their specific challenges without penalties for factors beyond their control, promoting broader participation and successful implementation.
- Excluding Unmanageable Emissions from the Methodology: The exclusion of emissions that companies cannot directly control aims to minimize distortions and create balanced, representative targets. This ensures that reduction efforts focus on emissions directly tied to operational actions while maintaining the integrity of SBTi metrics.
- Adopting a Dual Reporting Framework: Implementing dual reporting allows companies to distinguish between emissions they can influence and those governed by national regulations. This approach fosters transparency, accountability, and incremental progress while providing policymakers with critical data for regulatory reforms.
- Methodology for Renewable Power Utility Companies: Targets should prioritize the highest-emission categories in the value chain, such as asset construction and maintenance, using life cycle analysis methodologies. This ensures alignment with sector-specific challenges and encourages renewable energy companies to expand decarbonization efforts across their supply chains and the broader economy.
- Focus on Dynamic Adaptation and Strategic Planning: Companies with higher emission intensity must act more quickly and decisively to meet targets within established timelines. This requires strategic planning for accelerated reductions and emphasizes the importance of dynamic adaptation.
- Monitoring Percentage Reductions Instead of Absolute Emissions: Prioritizing percentage reductions over absolute $CO_{2e}$ emissions highlights operational efficiency and continuous improvement. This approach ensures progress remains measurable and aligned with sustainability strategies, even when absolute emissions remain stable due to external factors.

One limitation of the proposed methodology, as well as the SBTi, is the focus on meeting specific short- and long-term targets without considering the trajectory necessary to achieve them. Companies with higher emission levels may be recognized equally as those that have been steadily reducing emissions over time if they meet the target in the designated year. This could result in an uneven acknowledgment of sustained efforts by companies that have long been committed to decarbonization. Future research should address the importance of tracking progress continuously rather than focusing solely on compliance at key milestones.

Another limitation is related to predominantly renewable energy companies that are not currently expanding their generation capacity. Our methodology assumes that Scope 3 emissions are tied to the expansion of generation assets, leaving room for further investigation into how these companies can align with decarbonization targets when they are not expanding or are even reducing their generation. In the case of solar power, the majority of emissions arise from components such as glass and silicon. To avoid categorizing these emissions under "others", which would fall into the "cross-sector" category, we opted to allocate them to the chemical industry. Future research could further refine this allocation process.

Addressing Emissions from Technical and Non-Technical Losses is an essential area for further research. Companies with vertically integrated structures face challenges in managing emissions from technical and non-technical losses, suggesting that further analysis is required to address these additional complexities. Future studies should explore innovative solutions, such as advanced metering systems and smarter grid technologies, to mitigate these losses and reduce emissions in a cost-effective manner. Addressing this gap will help companies more accurately track and reduce emissions across their entire operations.

In conclusion, this study addresses the central questions regarding the challenges faced by companies in Brazil's power sector when implementing SBTs, with a particular focus on the limitations of the current SBTi methodology for the sector. The hypothesis that existing methodologies fail to adequately reflect the efforts of companies with a significant share of renewable energy and/or vertically integrated power companies is confirmed, as many of these companies, despite their high proportion of renewable assets, struggle to achieve favorable scores under the current framework. By proposing an adaptation of this methodology, this paper fills an important gap by suggesting a more context-specific approach for the Brazilian energy sector while also contributing to the development of more flexible and representative guidelines for companies in similar contexts.

**Author Contributions:** Conceptualization, H.B.B., B.S.G., A.A.d.S., P.G., C.C.B., J.E.N.d.R. and A.O.P.J.; Methodology, H.B.B., B.S.G., A.A.d.S., P.G., C.C.B. and A.O.P.J.; Validation, H.B.B., B.S.G. and A.A.d.S.; Formal analysis, H.B.B., B.S.G. and A.A.d.S.; Investigation, H.B.B., B.S.G., A.A.d.S., P.G., C.C.B., J.E.N.d.R. and A.O.P.J.; Resources, H.B.B., B.S.G., A.A.d.S., P.G., C.C.B. and A.O.P.J.; Writing—original draft, H.B.B., B.S.G. and A.A.d.S.; Writing—review & editing, H.B.B., B.S.G., A.A.d.S. and A.O.P.J.; Supervision, C.C.B., J.E.N.d.R. and A.O.P.J.; Project administration, C.C.B. and A.O.P.J. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Research, Development, and Innovation (PDI) Program of the Brazilian National Electric Energy Agency (ANEEL), grant number PD-00404-2304/2023. This initiative is a collaborative effort between Energisa S.A., WayCarbon Soluções Ambientais e Projetos de Carbono S.A., and a team of researchers from the Energy Planning Program at COPPE/UFRJ.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Conflicts of Interest:** Authors Alex Azevedo dos Santos, Priscila Grutzmacher, Caroline Cristine Botta were employed by the company Waycarbon Soluções Ambientais e Projetos de Carbono AS. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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