Far from the Clean Trillion: assessing financial needs and opportunities for the Energy Transition in Brazil

Abstract

The global emphasis on decarbonization has brought attention to Brazil, the seventh largest GHG emitter, and its potential to lead in the energy transition. This paper employs standard renewable energy scenarios, consolidating academic work and numerical data on affordable sources of clean energy finance in Brazil. The aim is to facilitate the qualitative alignment of financing supply and demand in the Brazilian environment. The study shows that, given current investment mandates and lending criteria, the resources needed for an effective energy transition are insufficient. The current financial landscape is between 1.4 and 2.3 times less than the amount needed. Institutional investors and lenders such as pension funds and banking institutions are hesitant to invest in renewable energy or grid infrastructure due to anticipated policy discontinuities. Moreover, there is a need for additional venture and investment capital to finance early-stage projects of innovative clean energy technologies. This research builds a framework that reflects the role and needs for accessibility of various financing sources and new intermediation channels in the energy transition, outlining how they should be implemented in Brazil.

Keywords:

Renewable sources, Electricity, Public policies, financing

1. Introduction

Evidence of climate change is more apparent worldwide, increasing the need for global energy security. However, to reduce greenhouse gas emissions (GHG), there must be a substantial shift towards sustainable energy and materials, along with large-scale carbon capture, use, and storage (Rashid et al., 2020). This transition will require a substantial volume in annual investments by 2030, with various regions contributing differently.

Brazil's role is critical in this shift, not only because it is the world's seventh-largest GHG emitter but also because of its potential to support global change. Half of the country's emissions, around 1,057 MtCO2e (metric tons of carbon dioxide equivalent), result from deforestation, and a significant portion from agriculture, transportation, energy, and other sectors (WRI, 2023). However, given its abundant natural resources, Brazil can play a significant role in sustainable progress and lead the global economy toward decarbonization. The country has a significant mix of renewable energy such as hydropower, biomass, wind, and solar (Aneel, 2022). This advantage also positions it as a likely leader in green hydrogen production, mainly due to its competitive renewable energy costs.

On the other hand, to fulfill the commitment made in the Paris Agreement to 2030, it is essential to attract more investments to the country, especially in renewable energy initiatives (Isah et al., 2023). Several companies are establishing their decarbonization commitments, and renewable energy is an easy and cost-effective option. But, it is crucial to evaluate whether the current resources will be sufficient to attain the objectives within the designated timeframe.

Works from Gielen (2017), Capros et al. (2018), and IEA (2020) reinforce the considerable investments needed to actualize the transition towards net-zero emissions, encompassing both mature technologies and innovative breakthroughs. According to the World Investment Report 2023, there is a growing annual investment gap that developing countries face as they work towards achieving the Sustainable Development Goals (SDGs) by 2030. The gap is now around US$ 4 trillion per year - up from US$ 2.5 trillion in 2015 when the SDGs were adopted. The document highlights that developing countries need renewable energy investments of around US$ 1.7 trillion a year but have attracted only US$ 544 billion in clean energy by 2022 (WIR, 2023). The Brazilian government estimates the need for investments amounting to roughly US$ 86 billion by 2031 (EPE, 2023*b*), highlighting the responsibility confronting policymakers to mobilize the resources.

This study aims to enrich the current literature and societal dialogue by concentrating on the available and required mix of financing sources. Despite prior studies by McCollum et al. (2018) and Polzin and Sanders (2020), the ideal composition of investments for Brazil still needs to be determined. Scholars such as Isah et al. (2023) have endeavored to address this issue, comparing Brazil with Nigeria, for example. In their study, the authors point out that the National Bank mainly drives the energy transition in Brazil, while in Nigeria, renewable projects are mainly financed by bilateral agencies and multilateral development banks. They concluded that instruments need restructuring to attract finance and optimize market opportunities. Drawing from these researchers' findings, this paper aims to address: What mix of resources should finance renewable energy projects in Brazil?

By systematically summarizing available transition paths and corresponding investment demands for Brazil, this paper seeks to answer this question. It exposes a current aggregate "financing gap" and a qualitative mismatch in Brazil. Specifically, there needs to be more private, small-scale equity investment for driving research, development, and demonstration of innovative technologies, along with more financing options for decentralized renewable energy projects. Exploring novel forms of intermediation and implementing reforms is necessary to overcome these challenges and unlock latent resources. By channeling financial resources to where they are most needed, Brazil can bolster its position as a leader in transitioning towards a sustainable and cleaner energy future while furthering the existing body of knowledge on financing renewable energy projects.

Following this introduction, the subsequent section situates this research within the Brazilian literature on renewable energy. Section 2 outlines the methodology for reviewing empirical, model-based evidence and relevant literature. Section 3 provides a current overview of the Brazilian energy sector and the directions for the energy transition in the country. In Section 4, the paper explores the challenges for renewable energy development in both centralized and distributed generation projects. The chapter also looks at the impacts of the Covid-19 pandemic on the energy transition and some strategies to overcome existing barriers. Section 5 delves into financial mechanisms for sustainable energy transition, discussing funding options for Early and Intermediate Stage Technologies, explicitly focusing on Brazil. It also explores optimizing financing for Mature Technologies, including the role of National Banks, Debentures, and Other Funding and Facilitating Mechanisms, concluding with a section summary. Section 6 presents a comprehensive discussion of the research aims, while Section 7 provides a conclusion that synthesizes the main findings and contributions of the paper.

2. Material and method

This research is anchored in a systematic narrative synthesis methodology (Popay et al., 2006). Initially, narratives on Brazilian energy investment needs were assembled, leveraging both historical data and existing future investment scenarios. Rather than presenting new energy transition scenarios, this paper primarily focuses on an array of established, widely cited models that generate energy sector projections. These models are critical as they provide quantified investment trajectories.

The methodology devised in this paper is applicable to any such scenario predictions and models. To illustrate its practical application, a select number of government documents, including policies, regulations, initiatives, and energy plans, were employed as principal information sources. The analysis was further enriched by data collected from energy companies' websites and official government databases. In particular, the Energy Research Company (EPE, 2023*b*) and the National Electric Energy Agency (Aneel, 2021) served as pivotal resources in this research undertaking.

Data obtained from the Energy Research Company (EPE) were instrumental in examining the energy transition within the electricity energy matrix. To deepen the financing aspect of energy transition technologies and discern the challenges inherent to each transition phase, consultations were held with national banks and agencies such as the National Bank for Economic and Social Development (BNDES, 2022) and ANEEL.

Through integrating these diverse sources, a holistic understanding of the energy transition process was obtained. As a result, this approach supported a robust analysis of the topic under study.

3. Energy Transition in Brazil

Brazil's journey towards renewable energy began with its establishment of hydroelectric plants during its industrialization period from 1930 to 1980. Since then, the country has strengthened its commitment to renewable energy, as indicated in Fig. 1. In 2022, Brazil managed to generate a record-breaking 92% of its total electricity from renewable sources (CCEE, 2023).

Although Brazil is known for its predominantly clean electricity matrix, the demand for decarbonization spans several other facets of the country's energy landscape. According to Lazaro et al. (2022), energy transition in emerging nations often necessitates a considerable increase in the availability and affordability of energy services. This could lead to an increase in carbon intensity associated with increases in economic development, urbanization, and industrial production, as well as due to the expansion of the transportation systems (Goldthau et al., 2020).

Moreover, with climate change influencing rainfall patterns, the reliability of hydroelec-

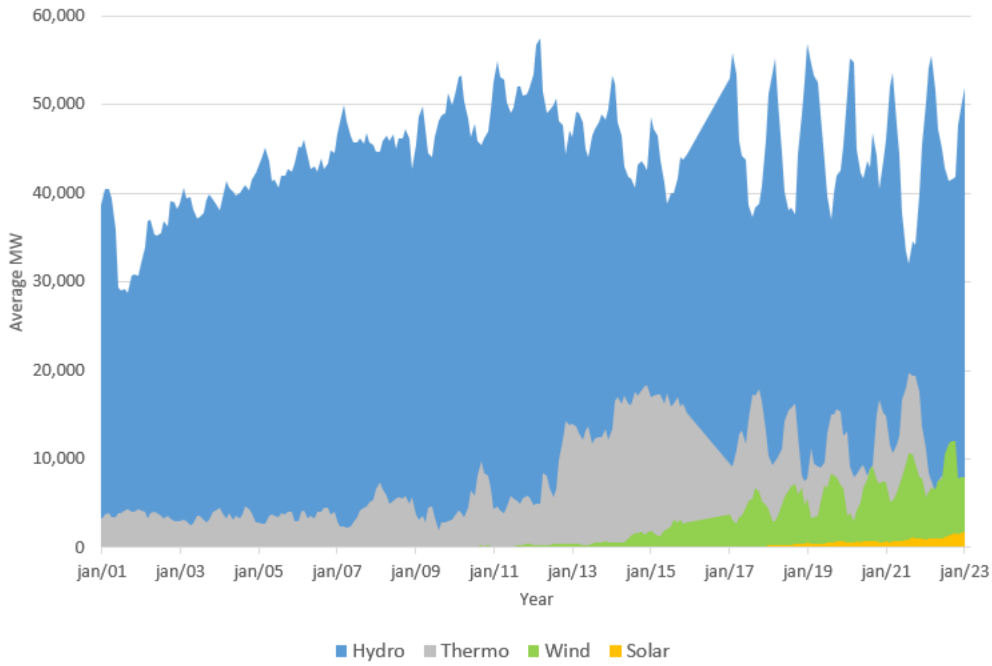

Figure 1: Brasil: Evolution of the Internal Energy Consumption and the electricity matrix in 2022. Source: Elaborated from ONS (2023) and (CCEE, 2023).

tricity may be under threat, underscoring the importance of further diversifying renewable energy sources (Souza Dias et al., 2018). Also, as a participant in global agreements, such as the Paris Agreement, Brazil has committed to measures to reduce its GHG emissions, requiring efforts across various economic sectors.

By advancing clean technologies, Brazil has the opportunity to establish itself as a leader on the global energy scene, offering economic opportunities and job prospects. In addition to directly reducing emissions, transitioning to a low-carbon economy can bring collateral benefits such as improved air quality, public health, and economic resilience. Therefore, the Brazilian electricity matrix is another side of the intricate decarbonization challenge. When considering the various sectors and the intrinsic benefits of an energy transition, it is clear that progress toward a cleaner energy matrix is essential and advantageous for the country.

3.1. The Energy Sector

Over the years, the country has undertaken policy initiatives to diversify its energy mix, primarily through adopting wind and solar power. These initiatives include long-term contracts through auctions and the provision of BNDES funding (see Fig. 2).

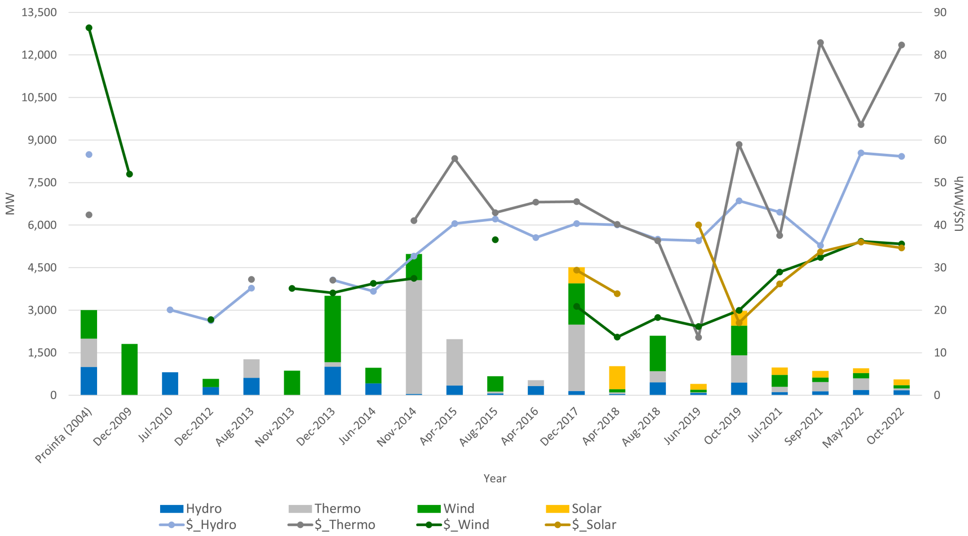

Figure 2: Evolution of power generation capacity in Brazil. Source: Elaborated from EPE (2023*a*).

Currently, Brazil is the sixth largest electricity generator in the world, with an installed capacity of approximately 192 GW, as can be seen in Fig. 3. During the years 2013 to 2022, the country made substantial investments in capacity, adding 58.83 MW - a growth of 37%. During this period, 16 GW of distributed generation (DG) capacity was added to the grid (EPE, 2022).

Wind power capacity increased from 7.7 GW in 2018 to 17.9 GW in 2021, while solar power capacity grew from 2 GW to 14.2 GW over the same period. This growth covers both large power plants and independent power generation systems. While the biomass sector also experienced considerable growth between 2008 and 2010, its contribution has declined over time (EPE, 2023*a*). Offshore wind power generation is still in its early stages in Brazil. According to Cebri (2021), Brazilian offshore wind technical potential is around 700 GW in locations with water depths of up to 50 m.

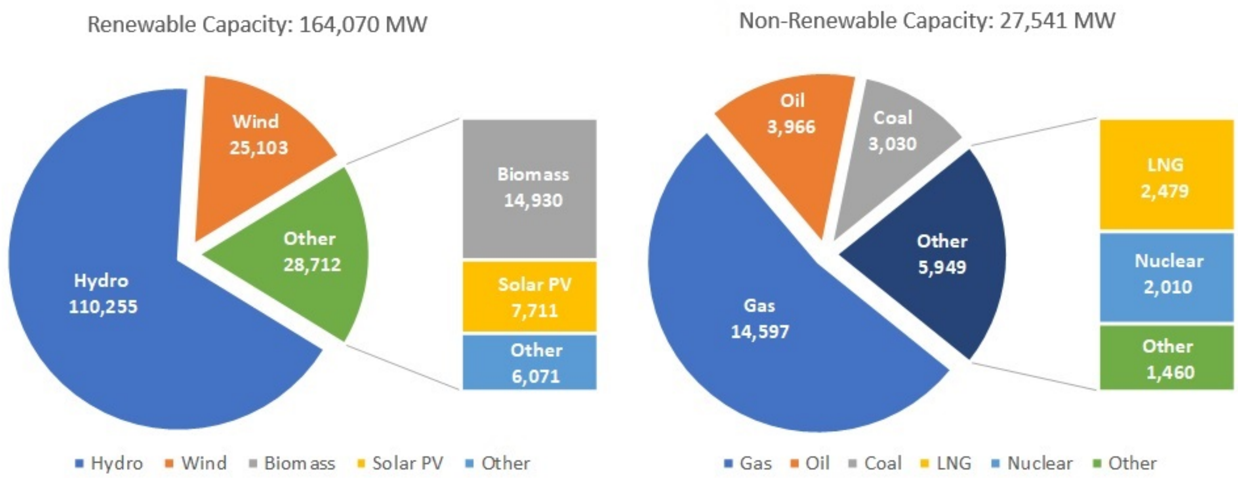

Figure 3: Installed capacity (MW) in 2022. Source: Elaborated from (EPE, 2022).

Wind power recorded the highest growth, benefiting from a favorable exchange rate and interest rate, coupled with excess capacity among international equipment manufacturers. By the end of 2016, the installed capacity of wind generation reached 10.7 GW, representing 7% of Brazil's total generation. As a result, Brazil ranked ninth in the world in installed wind power capacity and fifth in additional wind generation capacity installed that year (Abeeólica, 2017). Wind energy contract prices also dropped significantly, from an average of US$ 51.97/MWh in the initial auction to US$ 13.66/MWh in the April 2018 auction (considering updated prices and an exchange rate of 5.304 BRL/USD on 22.11.11, Central Bank of Brazil). Subsequently, the contract price increased due to the deterioration of macroeconomic conditions in Brazil.

Photovoltaic solar generation is the newest frontier, but it also presents pressing financing challenges (Ferreira, 2020). Solar energy has been consolidating its status as a viable cost-reduction solution, improving the security of electrical supply and boosting sustainability across the country. It is primarily generated by households, commercial and industrial establishments and connected to the distribution grid, classified as distributed generation (Vazquez and Hallack, 2018). According to Absolar (2023), the country saw a 49% increase in cumulative investments from 2012 to the end of 2020. By 2031, projected new investments could exceed US$ 57 billion, indicating a promising growth trajectory for this sector.

3.2. The Energy Future in Brazil

Brazil has a significant potential for renewable energy expansion, driving economic growth and environmental benefits. The Ten-Year Energy Plan (Plano Decenal de Energia - PDE) forecasts a 30% increase in Brazil's electricity supply, with a greater contribution from renewable sources, predominantly solar and wind, as well as natural gas and uranium. As described in the Plan, wind power generation is projected to increase by around 56% from 2021 to 2030. The share of non-renewable sources is expected to decrease in the coming years. The growth projection of the installed energy capacity in Brazil is represented in Figure 4.

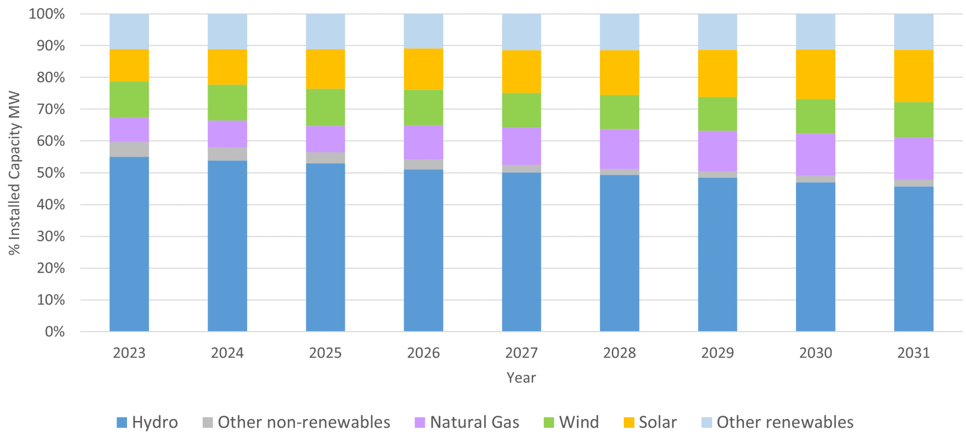

Figure 4: Projected installed capacity (MW) of electricity generation. Source: Elaborated from EPE (2023*b*).

The PDE estimates 35 GW of installed power in distributed generation, benefiting over four million generation units in Brazil by 2031, as shown in Fig. 5. Currently, the modality has over 16 GW operational. According to the study, solar photovoltaic technology remains the primary source in the distributed generation segment, accounting for about 93% of all expansion. In the projection, distributed generation, together with self-production, will represent 17% of the electricity matrix, estimated at 275 GW at the end of the ten-year horizon. It should contribute approximately 7% of the national load.

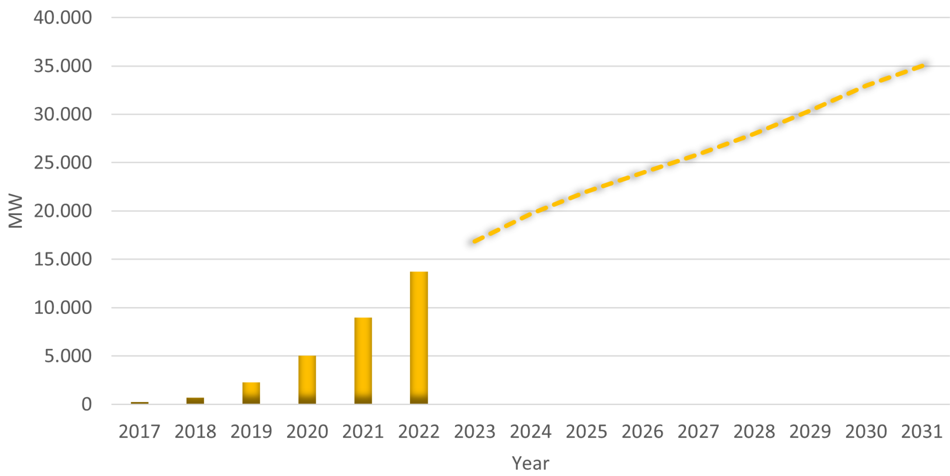

Figure 5: Installed Capacity DG. Source: Elaborated from EPE (2023*b*).

However, for Brazil to achieve its goals by 2030, a significant investment increase will be required. Expanding the installed capacity of centralized generation in Brazil will require investments of US$ 59.04 billion over the next ten years, while distributed generation will require an amount of US$ 27.23 billion (EPE, 2023*b*).

4. Barriers to Renewable Energy Development

Expanding renewable energy sources is a critical requirement for promoting sustainable development. However, multiple obstacles impede the progression of this sector. Addressing these barriers is vital to pave the way for a cleaner future.

The process of investing in new power plants involves choosing among various technologies and energy sources. This choice is based on an analysis comparing the lifetime electricity generation cost of different setups, known as the levelized cost of electricity (LCOE). This comparison is influenced by many technical factors such as capacity, operational costs, fuel prices, as well as maintenance and decommissioning costs (Shen et al., 2020).

A significant element of the LCOE is the capital cost, which can fluctuate among operators. On average, the total capital cost in developing nations could be seven times that in developed markets (IEA, 2021). This often gives an edge to international investors with access to lower-cost financing. Since the LCOE reflects the overall cost of producing electricity throughout a project's lifespan, future costs are reduced based on the capital cost (IEA, 2020). Higher capital costs increase the current cost of electricity generation, especially for projects that require high initial capital expenditure and have low operating costs, as future operational costs are discounted more than upfront expenses.

According to IEA (2022), the cost of capital can determine up to 50 percent of the LCOE in solar energy installations. In 2022, the capital cost for energy projects in developing countries was nearly triple that of developed countries. In Brazil, the cost of capital (based on debt) was almost 60 times higher than the lowest value in the European Union and the United States due to rising interest rates and investment-related challenges. This represents a substantial barrier to renewable energy once high capital costs discourage diversification into renewable energy investments.

Elevated financing costs are a significant obstacle to securing investment in renewable energy in developing nations (IRENA, 2022), and they depend on a variety of country-specific and project-specific factors, including project sponsors and off-takers. Hence, the ability of investors to access lower financing costs is an essential variable in accelerating the energy transition, especially in countries with relatively higher capital costs.

To address these challenges, a combined effort of governments, financial institutions, and project developers is crucial to promote renewable energy projects, whether centralized or distributed generation. In recent decades, the expansion of large-scale centralized generations has been seriously challenged by its high costs, environmental impacts, and some technical problems such as grid loss and security issues. On the other hand, the technological advancement of DG units, the global approach to reducing pollutant emissions, and the creation of opportunities for local investors to participate in the investment in generation expansion have involved DG as an alternative option in the planned generation expansion. In this regard, the barriers to the expansion of DG units compared to the expansion of centralized generation units will need to be assessed.

4.1. Centralized generation projects

The first barrier to the financing of centralized generation projects is related to subsidized public financing, which requires national content and has a low performance by multilateral organizations and development banks from other countries (Costa et al., 2022). These projects find it difficult to obtain more attractive rates with private financing, either from commercial banks or via capital markets.

There are also barriers associated with raising funds in the foreign market, including exchange rate risk and hedge costs. Also, information asymmetry is still an existing barrier due to the low knowledge of the structure of the projects and high perception of risk due to the auction model with the objective of tariff modicity, which puts pressure on the cash flow of the winning projects (Ferreira et al., 2019).

4.2. Distributed generation projects

Although Brazil has great potential for the growth of DG due to the abundance of the universally available energy source, there are still barriers to its complete structuring. For example, there is still low awareness of the technology and the potential economic advantages of self-generation (Sitawi and Cebds, 2016).

In addition, the high value of the investment concerning the annual energy savings results in a mismatch between the expected return on financing and the return on the project. There is also a need for lower-risk financing products for potential generating units and service providers. The financial institutions could increase internal competition with other products for small and medium-sized enterprises (Ferreira et al., 2019).

4.3. Impacts of the Covid-19 Pandemic

The uncertainty brought about by the volatile political and economic scenery in the post-pandemic era raised questions about the existing energy policies (Mello Delgado et al., 2021). For instance, Costa et al. (2022) examined that policies driven by socioeconomic factors during the Covid-19 pandemic significantly influenced the growth of wind and solar power in the country's energy matrix. In 2020, wind and solar energy sources grew by 7.6%, amounting to 11.5% of the internal electricity supply (EPE, 2020). But, the research also noticed the need for new policies to reinforce the presence of renewable energy.

The post-pandemic scenario presents uncertainties that necessitate continual oversight, mainly because the financial prosperity of green energy firms in Brazil is still heavily dependent on government incentives and political ties (Chen et al., 2021; Chien et al., 2021). Government subsidies act as market indicators for financial institutions, signifying investment opportunities, lower debt interest rates, and the firms' operational and total efficiency (Chien et al., 2021).

4.4. Overcoming Financial Barriers

Overcoming financial barriers requires a combination of policy interventions, support mechanisms, and incentives. Brazil has proactively addressed these barriers over the years. The primary measure adopted by the government was reforming the domestic electricity market in 2004 through Law 10.848/2004, which introduced significant changes such as "energy auctions" (Valle Costa et al., 2008; Brasília, 2004). These auctions have emerged as key policy instruments to expand and diversify the country's renewable energy supply (Fraundorfer and Rabitz, 2020; Andrade Santos et al., 2020). Since then, the government has used these auctions to contract new energy from sources such as sugarcane bagasse cogeneration, wind power, and solar photovoltaics (Fraundorfer and Rabitz, 2020; Elizondo Azuela et al., 2014; Porrua et al., 2010; Bayer, 2018).

In 2011, the Brazilian Electricity Regulatory Agency (Aneel) introduced an impactful economic incentive for the research and development (R&D) of solar PV energy through the Strategic Call for R&D nº 13 (Call 13/2011). The objective was to put forth technical and commercial frameworks for solar PV generation, thereby fostering the inclusion of this technology in Brazil's electrical grid (Santos Carstens and da Cunha, 2019).

Soon after this measure, the Agency published the Normative Resolution 482 of 2012, in which it formalized a compensation system for micro ($\leq$ 75 kW) and mini ($>$75 kW and $\leq$ 5 MW) distributed generation (DG) that employ qualified co-generation or renewable sources. The regulation, also known as the net-metering system, enables the system owner to pump surplus energy into the electrical network and accumulate energy credits (non-monetary, measured in kWh) to be used within a 60-month timeframe (Brasília, 2012, 2015).

In the meantime, fiscal incentives played an important role, specifically the discounts on the Tariff for the Use of Transmission Systems (TUST) and the Tariff for the Use of Distribution Systems (TUSD), along with the Brazilian National Finance Policy Council (CONFAZ) (MEB, 2015). Some renewable energy projects, including hydroelectric, solar PV, wind, biomass, or qualified co-generation, could potentially see a reduction in TUST and TUSD rates (Brasilia, 2003, 2004, 2003, 2021). Covenant 101, published in 2018, is another significant fiscal incentive as it exempts the incidence of the tax on the circulation of goods and services (ICMS) intended for electricity generation by PV cells and wind projects (CNPF, 2018).

An overview of current measures aimed at attracting investments, stimulating development and innovation, and promoting flexibility in the Brazilian energy structure is presented in Fig. 6. Fiscal incentives play a crucial role in attracting investments and facilitating project implementation. At the same time, public financing supports specialized credit for renewable energy projects. Innovation policies boost private investments in research, development, and innovation (RD&I), minimizing socio-environmental externalities. Collaboration in RD&I and the sharing of intellectual property are essential to invest in and disseminate technological innovations.

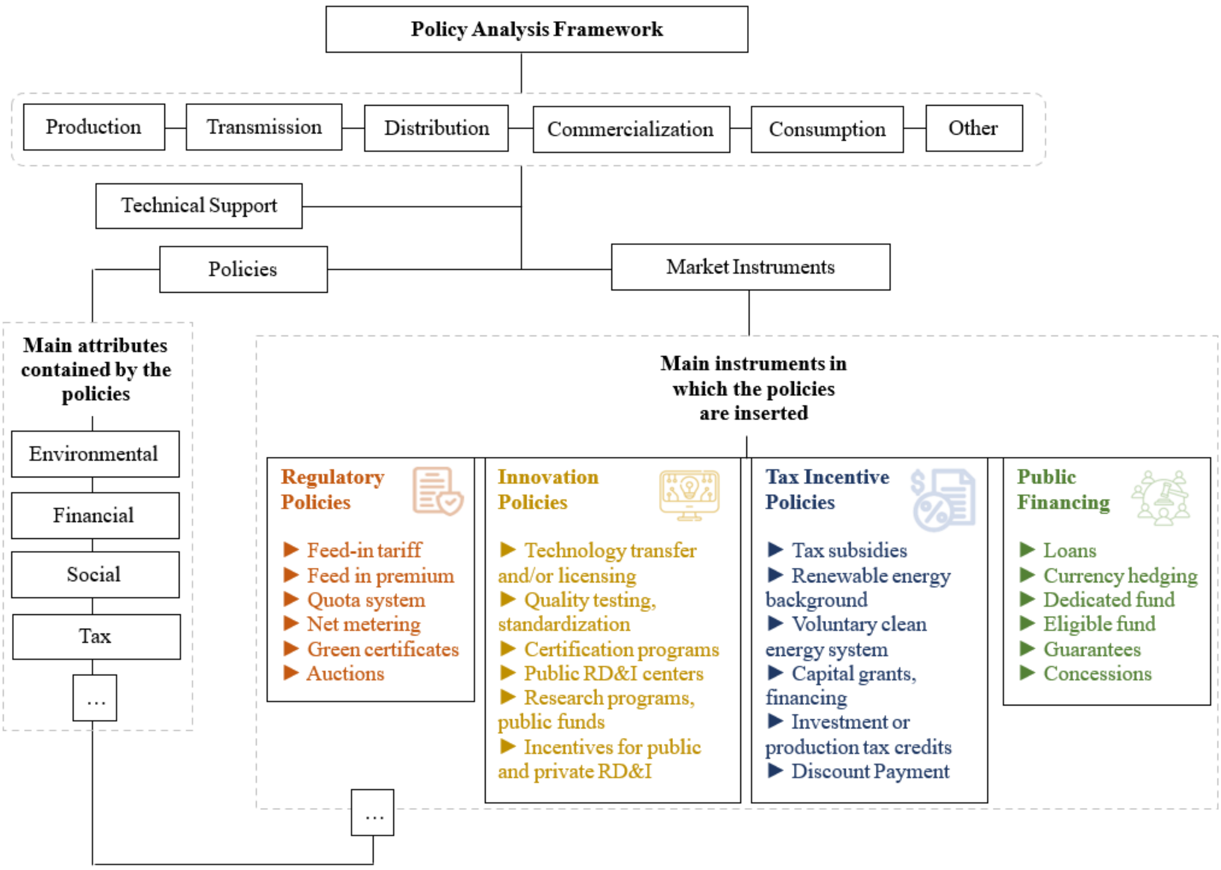

Figure 6: Market development instruments and their characteristics. Source: Adapted from Pagel et al. (2018) and Costa et al. (2022).

While Brazil has made progress in surpassing some of the sector's barriers, the growing need for investment in renewable energy projects still requires less government-centric solutions. In this sense, collaboration with financial institutions to create specialized financing products tailored to the sector is a potential solution. This could involve providing guarantees, credit enhancements, and risk-sharing mechanisms to reduce perceived risks and facilitate access to finance. In addition, encouraging financial institutions to adopt sustainable investment practices and consider environmental, social, and governance (ESG) criteria in their investment decisions can also boost the flow of capital to renewable energy projects.

Moreover, large-scale renewable energy projects could be supported using thematic funds and multilateral agencies such as the International Finance Corporation (IFC), Inter-American Development Bank (IDB), Agence Française de Développement (AFD), United States Agency for International Development (USAID), European Investment Bank (EIB), Kreditanstalt für Wiederaufbau (KfW), Global Environment Facility (GEF), Clean Technology Fund (CTF) and Green Climate Fund (GCF). This could be further facilitated by financial instruments and business models such as green bonds, YieldCos, standardized contracts, and private equity investment funds.

Implementing these proposals would create an investment-friendly institutional environment, generate the scale needed to attract investors and equipment manufacturers, and help Brazil achieve its renewable energy goals. Through these collective efforts, Brazil can accelerate its transition to a sustainable and resilient energy future.

5. Financial Mechanisms for the Sustainable Energy Transition in Brazil

The growth of renewable electricity generation systems is strongly driven by the availability of robust financing options. These options can strengthen enterprises and supply chains by reducing their vulnerability to international price fluctuations (Andrade Santos et al., 2020).

Financing mechanisms, however, differ across the various stages of renewable energy project development, which generally range from initial planning and feasibility assessment to construction, operation, and maintenance. To effectively categorize the maturity stages of renewable energy technologies, a classification framework similar to Foxon et al. (2005) was adopted as Fig. 7. This is because Brazilian innovation systems for renewable energy technologies, as well as Foxon's work, are characterized as non-linear and dynamic, presenting feedback loops at different stages of development.

Each technology stage demands a distinct level of financing, and mechanisms can be

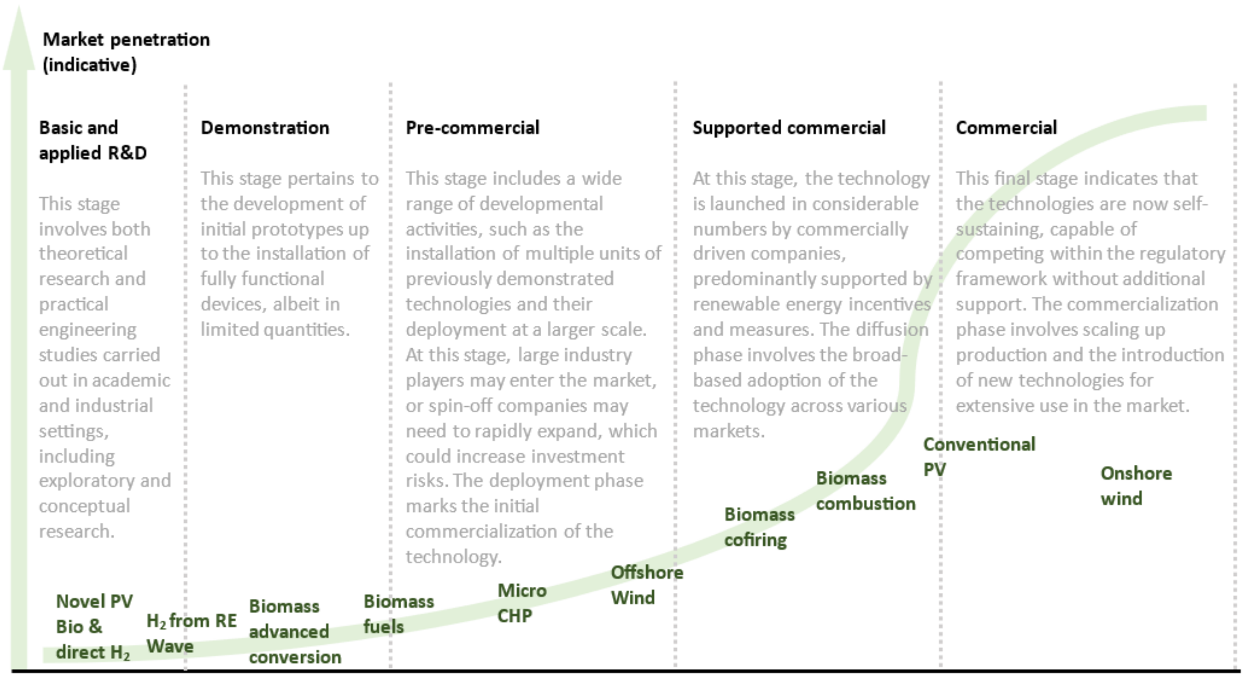

Figure 7: Technology maturity by "stage". Source: Adapted from Foxon et al. (2005).

leveraged to ensure consistent progress while mitigating financial risks. Recognizing these stages assists in pinpointing critical junctures in the innovation chain where system "gaps" may impede the successful commercialization of technologies. Nonetheless, it is crucial to note that the boundaries between these stages are not rigid, and defining technological maturity can be a complex task, particularly given the variations in technology designs at different stages of commercialization.

5.1. Funding Early and Intermediate Stage Technologies

The early stages of technology development comprise the R&D and demonstration phases. Innovation carried out in these stages plays a crucial role in driving countries' economic growth. However, financing early-stage technologies often presents substantial challenges in the market (WEF, 2018).

Obtaining such financing can be an arduous task due to the high costs related to these projects and uncertainties regarding scalability. In particular, banks are reluctant to invest in ventures with high-risk attributes, unproven business models, and nascent technologies, making it difficult for companies to secure the funds needed for development and expansion.

Hence, projects in the early stages rely mainly on government funding, specific R&D grants, and investments from small spin-outs or research subsidiaries. An example of government intervention is the Aneel R&D Program, from Law No. 9,991 of 2000, which is one of the impulses led by the government and the electricity companies so innovation is one of the pillars of this industry. This law determines that companies in the electricity sector must annually invest a percentage of their net operating revenue in R&D (Brasília, 2000). The initiative helps the sector to revitalize itself, resulting in an improvement in its deliveries, as well as increasing the added value of the entire energy production chain.

Besides ANEEL's R&D program, other Brazilian institutions provide funding for early-stage technologies. Table 1 shows real data for renewable energy projects coming from the National Agency of Petroleum, Natural Gas, and Biofuels (ANP), Brazilian Development Bank (BNDES) National Nuclear Energy Commission (CNEM), National Council for Scientific and Technological Development (CNPq), São Paulo State Research Foundation (FAPESP), Brazilian Innovation Agency (FINEP).

Table 1: Funding sources for early-stage maturity technologies (in million dollars).

Funding source	2013	2014	2015	2016	2017	2018	2019	2020
ANEEL	1288.10	1169.10	853.50	765.70	920.00	957.40	1072.50	1027.20
ANP	1971.00	1856.20	1457.20	1354.70	1633.60	2293.30	1650.90	1973.80
BNDES	278.40	514.70	405.30	518.00	486.70	496.40	461.80	430.80
CNEM	24.60	78.50	92.00	91.90	72.00	82.50	107.20	103.80
CNPq	53.80	38.50	58.40	44.00	31.80	34.30	18.50	26.40
FAPESP	28.00	27.40	22.30	18.30	21.20	21.90	22.00	17.50
FINEP	283.80	538.10	534.00	258.90	192.60	93.60	142.50	137.20
Total	3927.70	4222.50	3422.70	3051.50	3357.90	3979.40	3475.40	3716.70

Source: Inova-E (2023).

Other efforts are in progress to improve the funding for early-stage technologies in Brazil. The emergence of angel investor networks, crowdfunding platforms, and impact investment organizations may provide alternative funding for tech companies.

5.2. Funding Mature Technologies

In Brazil, some specific providers and mechanisms assist market development and create financial support for mature renewable technologies. In particular, the auction system is the most widely used mechanism to promote their financial support. Auctions are a way to establish long-term contracts to buy electricity from renewable energy sources at a predetermined price. These auctions have proven instrumental in attracting investment and reducing the costs of renewable energy projects (EPE, 2023*a*).

Banks

The BNDES is the main instrument for promoting long-term investments in the Brazilian economy. Since its foundation in 1952, the bank has offered special conditions for micro, small, and medium-sized enterprises. Currently, the BNDES is a diversified financial institution which grants loans directly to project developers and indirectly through partnerships with public financial institutions, such as Banco do Brasil and Caixa, regional banks, such as Banco Nordeste and Banco de Desenvolvimento de Minas Gerais, and private financial institutions (Tolmasquim et al., 2021)

Throughout its history, BNDES has been instrumental in promoting investments in new capacities and fostering the growth of a local capital goods supply industry. Acting as the main financier of renewable energy projects in Brazil, BNDES offers concessional financing of up to 80% of total project costs, with interest rates ranging from 7% to 9% and repayment terms of up to 20 years. Notably, in 2002, BNDES committed a sum of $2.3 billion to support PROINFA (Programa de Incentivo às Fontes Alternativas de Energia Elétrica) renewable energy projects, with the aim of incentivizing private investments (Leite, 2009). From 2004 to 2018, BNDES was responsible for more than 70% of the total debt financing for renewable energy projects in the country. In addition, the institution has successfully issued green bonds in international markets, using the proceeds to finance sustainable energy initiatives (BNDES, 2018).

Between 2010 and 2014, there was a rise in green finance, increasing from US$10 billion to US$12 billion. Nevertheless, between 2016 and 2018, grants decreased to an average of approximately US$4 billion annually due to restrictions on investment and policy guidelines aiming to decrease BNDES' involvement in the economy. Over time, there has been a significant shift in the structure of green financing, leaning towards emerging energy sources. The proportion of hydropower plants substantially declined from 34.4% in 2010 to 7.3% in 2018. On the other hand, wind, solar, and biomass sources saw a rising, surging from 33.3% in 2010 to 46.3% in 2018. Consequently, during the period from 2010 to 2018, renewable energies constituted 32.6% of the overall green financing (Ferraz et al., 2022).

The achievements of BNDES in the field of clean energy have garnered global recognition. Between 2004 and 2019, BNDES held the largest debt portfolio in clean energy worldwide, amounting to US$31.3 billion. Santander and MUFG (Mitsubishi UFJ Financial Group, Inc.) followed closely behind. In comparison, other entities like the European Investment Bank, KfW Bankengruppe, Mizuho Financial, and Société Générale had portfolios ranging from US$11 billion to US$19 billion (Bloomberg/NEF, 2020). Fig. 8 provides a visual representation of the different sources of bank financing available for the energy transition, linking them to investment characteristics.

Preparing for the future, in early 2023, BNDES approved financing for the implementation of two wind and one solar complex, as well as the associated transmission lines, in the northeast and southeast regions of Brazil. Totaling 1.5 GW in installed capacity, total investments reach BRL 10.6 billion. The BNDES participation of R$ 3.5 billion will occur through the BNDES Finem program. The energy generated by the plants will be equivalent to that needed to meet about 8.6 million tons of CO2 emissions avoided over the lifetime of the projects. The projects contribute to the increase in installed capacity in renewable

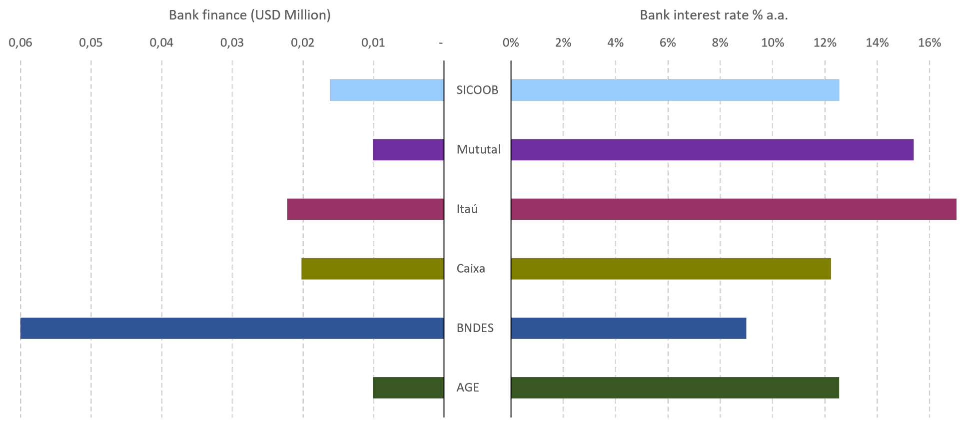

Figure 8: Comparison of bank loans and rates for renewable energy projects. Source: Banks' websites.

energy and to the development of the energy market in the country (BNDES, 2023*b*).

Also this year, the BNDES approved financing in the amount of R$ 700 million for the implementation of 49 new photovoltaic plants, in the distributed generation modality, in the southeast and central-west regions of Brazil. This is the Bank's largest financing for a renewable source distributed generation project. The project will contribute to adding approximately 144 MWAC (mega-watt alternating current) of electrical power close to the point of consumption, from a clean and renewable source (BNDES, 2023*a*).

Debentures

In recent times, sustainable finance in Brazil has seen the emergence of green bonds as a prominent vehicle. Institutional investors have been instrumental in driving the development and growth of this market. The appeal of the green label lies in its ability to enable investors to direct funds toward climate and environmental projects, offering greater transparency (MME, 2022).

Green bonds first came to the market in 2007 and have since proven to be effective in mobilizing investments for low-carbon solutions. Globally, the issuance of green bonds has surpassed US$1.2 trillion to date, with US$297 billion issued in 2020 and US$155 billion issued by June 2021. In the Latin America and Caribbean region, cumulative issuances have reached US$26.3 billion (CBI, 2019). Notably, Brazil stands out as the largest green bond market in the region, with US$9 billion in total issuance. The country's first green bond was introduced in June 2015, leading to 60 issuances since then, focusing on investments in renewable energy, agriculture, and infrastructure sectors. These green bonds typically have maturities ranging from 5 to 10 years, especially for larger deals (CFA, 2022).

Renewable energy generation historically accounts for over half of all energy infrastructure projects supported by debenture bonds (MME, 2022). Around 53% of the capital expenditures (Capex) portion supported by debentures is allocated to renewable generation projects. Grid investments are also significant for integrating new resources, accounting for 21% of energy infrastructure. For energy infrastructure projects, the average bond ticket size is $69 million. This amount represents over half of the total capital expenditures among bond issuers, indicating the instrument's suitability for large-sized projects (MME, 2022). Currently, BNDES and infrastructure debenture bonds are the main sources of debt funding for mature technologies, as illustrated in Fig. 9.

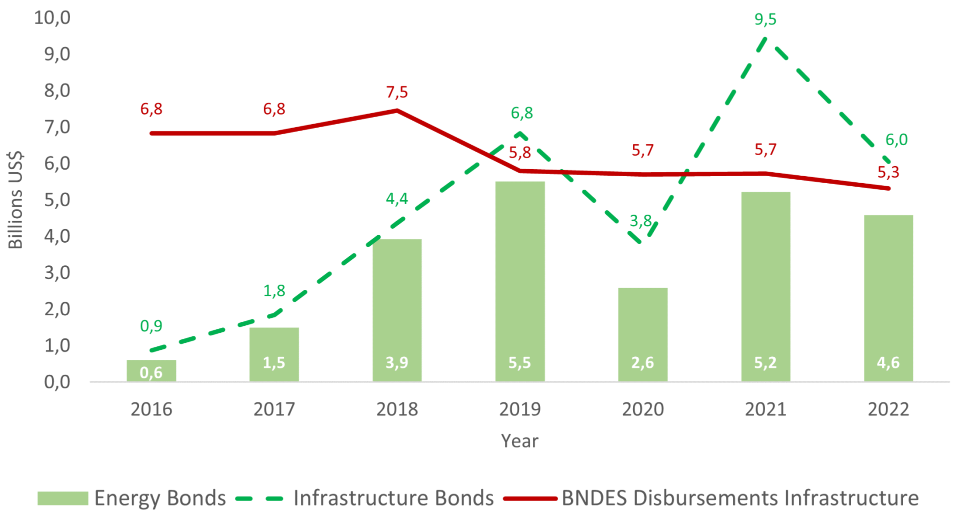

Figure 9: BNDES and infrastructure debenture bonds comparison. Source: Elaborated from EPE (2021).

Brazil has a considerable pipeline of green projects that can be funded through green bonds. According to CBI (2020) there are various investment prospects in renewable energy, agriculture, and infrastructure sectors. In particular, there is an estimated US$163.3 billion opportunities in sustainable agriculture activities over the upcoming decade. As a result, the potential for growth in the Brazilian green bond market is substantial.

Other Facilitating Mechanisms

Green projects span multiple technologies at various stages of maturity, requiring diverse financing approaches. Some practical solutions include increasing the role of public and non-banking financial institutions (pension funds and insurance companies) in long-term green investments (Taghizadeh-Hesary and Yoshino, 2020).

The growth of renewable energy is fueled by several factors, such as policy incentives through support schemes like feed-in tariffs, as well as advancements in technology leading to improved reliability. However, investments in renewables face growing complexities in terms of risks. To mitigate these risks and safeguard cash flows, having sufficient insurance and risk management instruments is crucial. This is especially vital for institutional investors like insurers and pension funds, ensuring the sustainable growth of renewable energy projects (Gatzert and Kosub, 2016).

Pension funds and insurance companies offer distinct advantages over banks due to their focus on asset-liability matching and the availability of long-term resources spanning several decades (e.g., 10, 20, or 40 years). With such extended horizons, insurance companies and pension funds are well-suited to finance infrastructure initiatives, including major green energy projects like large-scale hydropower, as these projects typically span over a long-term period (10-20 years). As a result, these institutions can play a significant role in bridging the financing gap for infrastructure projects, encompassing energy and green energy initiatives, and ensuring sustainable funding for critical developments (Yoshino and Taghizadeh-Hesary, 2018).

However, despite the growing interest in these financial instruments pension funds' allocation to green investments remains relatively low. This is partly due to a lack of environmental policy support, as well as other barriers such as the absence of suitable investment vehicles and market liquidity, scale-related challenges, regulatory disincentives, and limited knowledge, track record, and expertise among pension funds regarding these investments and their associated risks (Della Croce et al., 2011).

More recently, there has been a notable increase in sovereign wealth funds, some of which explicitly aim to invest ethically by considering the social and environmental implications of their investments. In particular, Abu Dhabi's Mubadala Capital plans to invest US$2.4 billion over ten years to build a green diesel and sustainable aviation kerosene factory in Brazil's northeastern Bahia (Bloomberg, 2023). Also, Brazil is a primary recipient of Norwegian investments, where the value of accumulated investments is US$ 32.5 billion, and 71% of that is invested in the energy sector (TPR, 2022).

On the other hand, to exploit this source of capital, the government has a vital role in ensuring the availability of attractive opportunities and instruments for pension funds and institutional investors. As global green markets evolve, Brazil needs to follow up with increasing clarity on how proceeds are used through annual reporting to bond maturity (Shishlov et al., 2016). In this sense, the establishment and harmonization of international standards can facilitate this process, allowing financial institutions to give an efficient "green label" to their portfolios and expand green financing opportunities.

Regulatory improvements aimed at strengthening and maturing the domestic capital market can promote sustainable finance. Recent measures, such as Decree 10.387/20 to streamline green debentures and Law 13.986/20 allowing the issuance of CRAs in hard currencies, are examples of regulations that can contribute to the growth of this market (Brasília, 2020*a*,*b*).

Private capital also plays an increasingly significant role in the energy sector. Financial institutions could focus on providing risk mitigation frameworks and guarantees to support green projects where their influence can be most effective.

5.3. Summary

The previous sections examine in detail a variety of financial resources that are part of the energy transition in Brazil, with a specific emphasis on investments in the energy sector. These resources are then compared to the projected demand outlined in the scenario studies of PDE 2031. However, it is important to note that there is an imperfect alignment between the sources of funding and investments that need funding. The financial structuring of individual projects involves numerous unique factors, making a precise matching impractical.

The analysis of the literature review highlights the need to increase the number of potential sources of funding for the different phases of the technologies essential for a successful energy transition. Fig. 10 provides a comprehensive overview of the significant financing gaps and existing debt funding sources, along with other instrumental supports for renewable technologies. These gaps pertain to different stages of technological maturity. Note that the current financing mechanisms may not completely bridge them.

It is essential fostering an enabling market environment for new technologies and emerging business models in the energy sector, alongside the potential for enhancing financial mechanisms. Diversifying funding sources holds promise for the progress and implementation of mature technologies in Brazil. Table 2 presents a comprehensive overview of finance supply from various sources in the country. The data collected reveals an average annual investment availability of between 37 and 61 billion dollars in renewable energies, which unfortunately falls short of the expected average needed to meet GHG reduction commitments by 2031. Therefore, as the renewable energy sector continues to evolve, financing mechanisms are expected to play a pivotal role in shaping the future trajectory of renewable energy in the country.

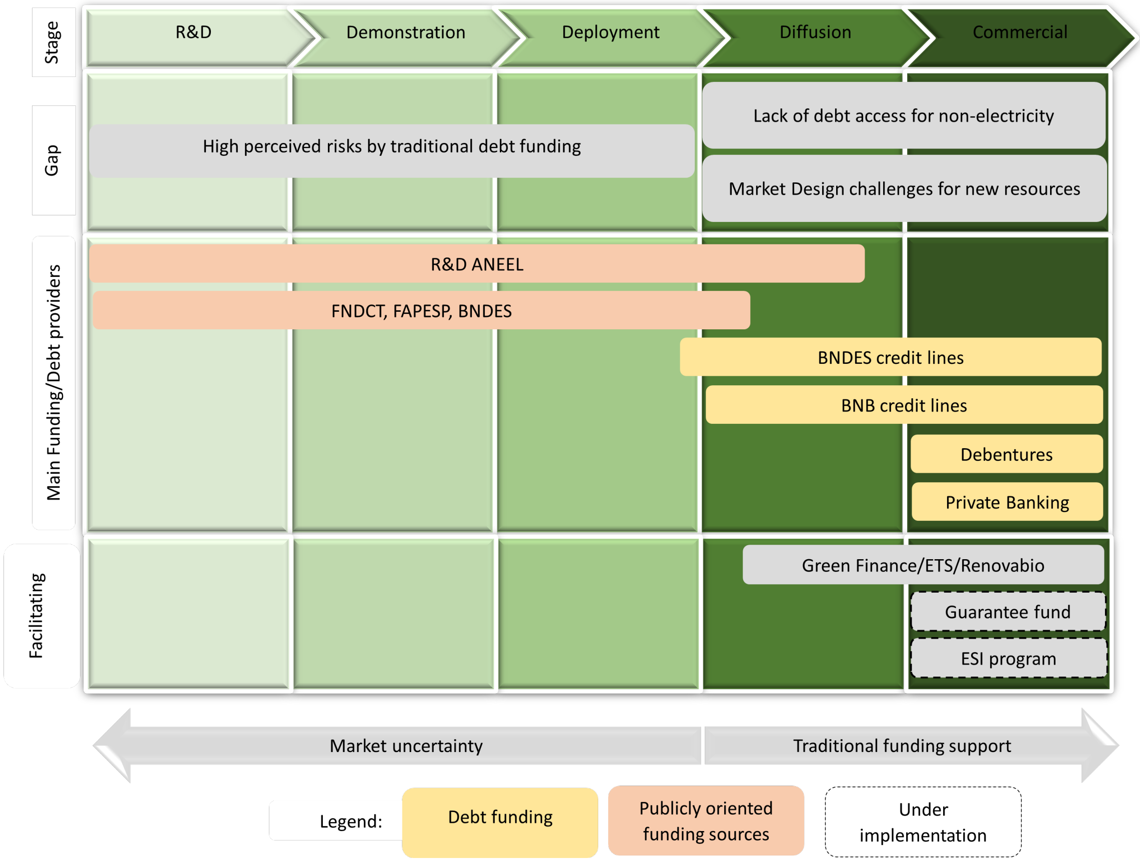

Figure 10: Maturity stage of Technologies, gaps and main financing instruments in Brazil Source: EPE (2021).
*ANEEL - Brazilian Electricity Regulatory Agency; FNDCT - National Fund for Scientific and Technological Development; FAPESP - São Paulo Research Foundation; BNDES - Brazilian Development Bank; ETS - Emissions Trading Scheme.

6. Discussion

The objective of this study is to verify the projection of private capital needed for a low-carbon energy transition in Brazil by the middle of this century and to suggest effective strategies to raise this capital. Drawing on empirical evidence and theoretical models from existing literature, the study seeks to bridge the gap between the need for investment and the potential sources of such financing for Brazil's energy evolution. The approach systematically explores possible sources of financing and highlights key actors critical to fostering

Table 2: Finance supply across sources.

Funding source	Average (USDbn)	Period	Source
Infrastructure Bonds	124.8	2012-2022	MME (2022)
Public Equity	>100	2003-2022	MME (2023)
Green/ Climate Bonds	30.8	2015-2022	NINT (2023)
Distributed Generation	21.2	2014-2020	EPE (2023*b*)
Research and Development	29.2	2013-2020	EBP (2023)
Sovereign Wealth Funds	6.9	2020-2023	Bloomberg (2023), TPR (2022)
Private Equity	2.2	2020-2021	ABVCAP (2023)
Pension Funds	>0.1	2023	*PREVI.* (2023), *FUNPRESP.* (2023), *PETROS.* (2023)
Insurers	1% of the investment value	2023	*Zurich.* (2023), *Mapfre.* (2023), *Tokio.* (2023)
State Investment Banks	>0.2	2023	Santander (2023), Bradesco (2023), Caixa (2023), BB (2023)
Bank Finance	>0.01	2023	Santander (2023), Bradesco (2023), Caixa (2023), BB (2023)

an innovative energy transformation. The study's findings indicate a need for the required financing, with a significant share expected from institutional investors.

Fig. 11 graphically presents the average provision of the different sources of finance for the energy transformation, related to their investment characteristics (see Table 2). The blue color signifies the most favorable conditions for institutional investors, which include wind farms, large-scale solar photovoltaic, and first-generation biofuel refineries, as well as transmission and distribution infrastructure. These investments are sizable and have minimal operational, market, and regulatory risks, with a stable cash flow and a low-risk profile. This sector also encompasses manufacturers of components for wind and solar energy or energy efficiency services, as represented by the figure as the predominant sources of financing.

Given the current mix of equities, bonds, and alternative investments, it is clear that institutional investors are well-placed to provide financing for large-scale renewable energy developments and grid infrastructure (Röttgers et al., 2018). A reshaping of the regulatory and governance landscape to encourage institutional investors to engage in non-public, long-term equity and green debt could unlock the vital financing needed for the proliferation of technologies that enable the transition. Investment processes can be simplified through intermediaries such as green bonds or YieldCos, thereby inviting more active participation of institutional investors in public equity markets (Tian, 2018).

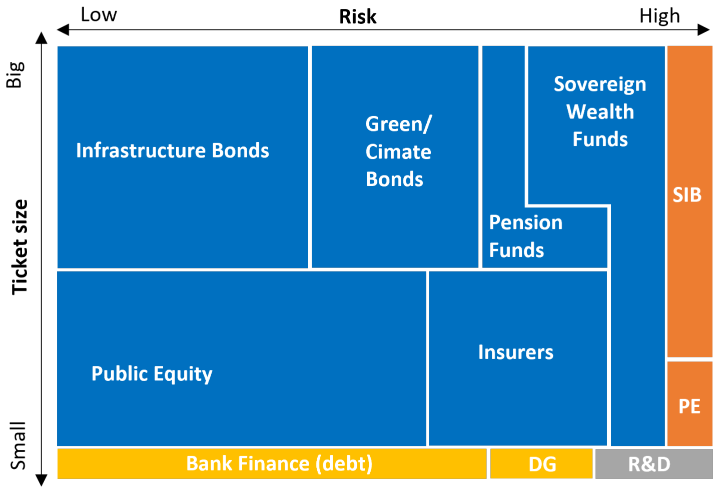

Figure 11: Availability of sources of finance for the energy transition in Brazil (framework adapted from Polzin and Sanders (2020); Note: the relative size of the rectangles represents the average availability per source of finance according to Table 2, where PE stands for Private Equity, and SIB stands for State Investment Banks.

The grey color signifies the financing of cutting-edge technologies, such as fuel cells or energy storage, which are currently at an early demonstration stage and present considerable technical and market risks. This stage also represents technological breakthroughs that can aid the integration of intermittent and low-intensity renewables into the electricity grid. However, during the early stages of the technology lifecycle, the funding gap becomes more pronounced, especially for high-risk investments. It is a challenging proposition to secure funds from conventional sources due to substantial technical and commercial uncertainties inherent in early-stage technology development (Polzin et al., 2021). Consequently, targeted policies, sector-specific programs, and niche investors often become indispensable in financing these new technologies. Potential shortfalls in innovation financing, especially R&D and private equity, are observed at this stage. While the amounts needed are smaller, the downstream impacts of the shortage are substantial. Neglecting early-stage development and knowledge diffusion may result in reduced learning effects, which are crucial to managing the costs of the energy transition.

There are no significant bottlenecks in the distribution of resources. However, mobilizing the appropriate types of financing for these projects can be challenging in a financial sector heavily reliant on institutionalized banks. Riskier, large-scale investments can be efficiently managed by investment banks and some private equity funds. While public sector banks could considerably increase their investments, their main role would likely be to mobilize private finance through co-investments, signaling, and education (Geddes et al., 2018; Mazzucato and Penna, 2015).

The orange color indicates "hard-to-finance" projects and ventures that combine large scale with high risks, such as offshore wind farms, advanced biofuels, and the first commercial plants of unproven technologies. On the other hand, for low-risk, small-scale projects (represented by the color yellow), mainly in the domains of energy efficiency and residential building improvements, conventional banks and crowdfunding based on contemporary platforms can be effective (Lam and Law, 2016; Appiah-Otoo et al., 2022). For the latter category, the financial sector's innovation becomes a crucial tool for policymaking.

7. Conclusion and Policy Implications

Brazil needs to advance its financial structures to increase renewable energy capacity further and achieve its Paris Agreement commitments. This research, by exploring the demand and availability of clean energy finance in the country, indicates that the future challenge lies not only in the scarcity of finance but also in effectively matching the demand and supply of investments. The necessary resources need to be more available in the desired forms, such as the need for private equity investments aimed at scaling up early-stage technologies. In addition, it is perceived that significant investments in low-risk debt need to be adequately channeled into renewable energy projects and energy infrastructure. Harnessing underutilized small- and large-scale sources through new forms of intermediation and regulatory and normative reforms could facilitate Brazil's energy transition. This transition must rely on more than public funding, and it is critical to incorporate the private sector.

This research posits that meeting the country's financial commitments is also a supply-side issue, as the necessary financial resources exist with specific constraints and investment preferences. Therefore, policymakers can work from two angles to mobilize private finance for the energy transition: policies explicitly targeting the domestic energy sector and those targeting diverse sources of finance.

Almost all investment scenarios compatible with a 1.5°C pathway rely on implementing policies promoting clean energy innovation and diffusion. Then, policies enacted must consider the ramifications for different types of investors. The effectiveness of policy programs depends heavily on their long-term consistency and reliability, often more than the amount of public funds invested. If governments can deepen their understanding of the realities of different funding sources, they can tailor critical energy transition policies to minimize political risk, a significant impediment to investment. As a result, a well-planned and executed transition can be less costly, faster, and more financially sustainable.

This study also highlights the role of the Brazilian government in financing innovation (R&D) and the need to halt the declining trend in this area. Innovations are crucial in developing sustainable solutions for increasingly complex and dynamic energy systems. Thus, given the funding gap for numerous clean energy innovation projects and the inherent requirement to accelerate known technologies, grants and public procurement should fund a significant part of these initiatives. Other measures to support innovation and learning include public loans and equity investments. Since different technological solutions carry varying levels of risk, ensuring that innovators have access to finance is critical.

About small-scale finance, policymakers need to strike a balance between protecting individual investors and creating new financial vehicles that attract them. One possible approach would be reducing mandatory pension fund savings, freeing up these resources for long-term investments, or supporting experimentation through small-scale finance.

Governments must deepen their understanding of institutional investors' behaviors and constraints for large-scale investments. For example, pension funds operate under specific regulations and adhere to a risk-return profile. Policymakers should design measures that reflect these realities. Policy interventions could include adjusting risk ratings to incorporate climate-related risks and providing credit enhancement mechanisms to reduce the perceived risk for clean energy projects. Green bonds, an increasingly popular financial instrument, could be another area of focus as they can offer a significant source of large-scale low-risk debt for renewable energy projects. To mitigate investment risks, blended finance tools and public-private co-investment instruments can be effective.

In conclusion, Brazil needs substantial financial resources that can be leveraged to transition to a clean energy economy. However, this transition requires a systemic approach that understands and caters to the nuances of different financial sources and investors. Government involvement is crucial as a catalyst for public funding for innovation and an enabler of private investment through regulatory reforms and risk mitigation. In addition, maintaining a long-term political vision and consistent policy implementation is critical to attracting investors and realizing the transition.

Brazil can stimulate renewables growth by adjusting financing conditions without stifling technological innovation. The insights in this article aim to inform policymakers and business practitioners on ways to accelerate the development of Brazil's sustainable energy sector. The journey toward a successful and sustainable energy transition requires a comprehensive vision, a sustained commitment to innovation, sustainability, and efficiency, and the determination to address and overcome existing challenges.

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