Risks, Rates, and Rays: The Financial Realities of Brazil's Solar Revolution

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Abstract

Solar photovoltaic (PV) is the fastest growing electricity source by capacity, with global additions reaching 600 GW in 2024. At the same time, rising interest rates adversely affect solar PV's competitiveness. This study examines the financial dynamics of Brazil's solar energy sector, focusing on how financing conditions impact the Levelised Cost of Energy (LCOE) for solar PV projects. Brazil's Weighted Average Cost of Capital (WACC) is significantly higher than in advanced economies, ranging from 10%–15% compared to 2.5% in Germany. Using a three-tiered methodology, we estimate the nominal after-tax Weighted Average Cost of Capital (WACC) for solar PV projects in Brazil, calculate the LCOE for projects awarded in energy auctions from 2014 to 2022, and projects financing scenarios for 2024 to 2029. Despite a 35% decline in CAPEX over the study period, financing costs increased from 47% of total project costs in 2014 to 62% in 2022, offsetting CAPEX and OPEX reductions and limiting LCOE improvements. Scenario analysis predicts that financing costs could range from 38% to 55% of total project costs by 2029, depending on macroeconomic conditions. The study also introduces intra-annual granularity in WACC estimates, capturing short-term economic fluctuations for greater accuracy. These findings underscore the critical role of macroeconomic stability and targeted financial strategies in achieving cost-effective solar PV deployment in Brazil and other emerging markets.

Keywords

Weighted Average Cost of Capital (WACC); Capex; Opex; Cost of debt; Cost of equity; Levelised Cost of Electricity (LCOE); Solar PV; Auctions; Future Projections; Interest Rates; Emerging Markets; Macroeconomic Conditions

Introduction

The global power sector is rapidly shifting to address climate change. Solar photovoltaic (PV) energy has become central to this shift, experiencing unprecedented growth and cost reductions, and is now the cheapest electricity source (IEA, 2024b). Global installation rates rose from one gigawatt annually in 2004 to an estimated 520-655 gigawatts in 2024 (The Economist, 2024). According to the (IEA, 2024b), this trend continues, with solar projected to attract over USD 500bn in investment by 2024. The exponential growth of solar PV stems from a cycle of increasing production, demand-pull policies, falling costs through economies of scale and learning-by-doing, and rising demand (Nemet, 2019).

Brazil, with its vast landmass and high solar irradiation, up to 6.5 kWh/m^2/day (Pereira et al., 2017), is well-positioned to use solar PV to meet rising energy demands and supporting decarbonisation. Despite this potential, significant growth in Brazil's solar PV capacity only started in the early 2010s, reaching 19% of total installed electricity capacity in Brazil by 2023 and becoming the second-largest source of electricity (ANEEL-SIGA, 2024a, 2024b). This rapid growth has been driven by declining technology costs, supportive policies like energy auctions or financing incentives by the Brazilian Development Bank (BNDES), and the introduction of net metering regulations (Iglesias & Vilaça, 2022). This expansion is critical for meeting rising electricity demand and diversifying an energy mix – long dominated by hydropower – a necessity highlighted by severe droughts that caused the 2001-2002 energy crisis (Carstens & Cunha, 2019).

Despite Brazil's solar PV growth, challenges remain with grid integration, permitting delays, and significant financing constraints (Damasio, 2024). The cost of capital for Brazilian solar PV can be two to three times higher than in advanced economies, reducing competitiveness (IEA, 2024a). This issue is further exacerbated by rising global interest rates, ending the 'zero era' of low rates (Martin et al., 2024). Limited understanding of how macroeconomic factors influence the cost of capital for solar PV projects in Brazil compounds the problem. Higher interest rates risk leading to suboptimal investments, inefficient resource allocation, and missed opportunities to accelerate Brazil's energy transition. Understanding these dynamics is vital for policymakers and investors, as a lack of context-specific data on the relationship between macroeconomic factors and capital costs hinders the development of effective policies and incentives to support sector growth.

This research addresses this gap by providing a detailed, context-specific analysis of how financing conditions shape solar PV project costs in Brazil, particularly highlighting the challenges faced by emerging markets. It also introduces intra-annual granularity by estimating a monthly weighted average cost of capital (WACC). This approach overcomes the limitations of studies using yearly estimates, lagging data, or failure to capture real-time fluctuations in financing conditions, ensuring short-term economic changes are reflected. Additionally, the research offers forward-looking insights into Brazil's solar PV sector evolution under different economic conditions, enabling investors and policymakers to craft long-term strategies.

This focus aligns with the study’s primary aim of analysing how macroeconomic shifts – such as interest rate fluctuations – impact the cost of capital for solar PV projects in Brazil from 2014 to 2024, a period marked by significant macroeconomic changes. A model was developed to quantify the relationship between interest rates and the WACC, considering inflation, currency fluctuations, and policy shifts. The study explores different interest rate scenarios to assess their implications for future financing costs and of solar PV projects competitiveness. These findings provide empirical insights to help policymakers and investors navigate interest rate fluctuations, supporting more effective renewable energy financing strategies tailored to Brazil's context and comparable economies.

Background

Macroeconomic landscape

Over the past two decades, Brazil has experienced significant economic fluctuations, characterised by periods of robust growth and deep recessions. The 'Brief Golden Age' in the early 2000s saw GDP growth averaging 4.5% annually, driven by a commodities boom and social programs boosting domestic consumption (Serrano & Summa, 2022; Gerard et al., 2021). However, from 2011 onward, economic strain set in due to declining commodity prices, rising labour costs, the appreciation of the Brazilian real and falling public revenues, leading to fiscal imbalances and inflationary pressures (Vartanian & Garbe, 2019). This culminated in Brazil's worst recession in recent history during 2015-2016 with GDP contractions of over 3% and soaring unemployment (IBGE, 2024). The COVID-19 pandemic further contracted GDP by 4.1% in 2020, and while recovery followed with 4.6% growth in 2021, challenges like uneven economic benefits and persistent unemployment continued (Ministério de Minas e Energia (MME), 2024).

By 2022, Brazil's central bank raised the Selic rate (i.e., the central bank rate) to 13.75% to curb inflation, impacting investments in sectors like renewable energy (Martin et al., 2024). Solar PV projects rely heavily on upfront investment, making them sensitive to interest rate fluctuations (IEA, 2024a; Schmidt et al., 2019a). The high cost of capital poses significant hurdles for solar PV financing, often twice as high as in advanced economies, largely due to macroeconomic factors and country-specific risks (IEA, 2024a). While clean energy investment has risen, high capital costs still hinder faster renewable energy deployment in the country (see Figure A12).

Furthermore, Brazil's fiscal landscape is marked by high public debt, rising from 60% of GDP in 2011 to 85% by 2024 (see Figure A13), and projected to reach 95% by 2029, increasing vulnerability to external shocks and exerting upward pressure on the cost of capital (IEA, 2024a; IMF, 2024). Brazil has a rigid budget structure, with government spending largely constitutionally mandated, thus efforts like the 2016 spending cap aimed at fiscal discipline, limited public investment. This has led to Lula's 2023 'Sustainable Fiscal Regime', promoting more flexible spending rules (Federal Government Brazil, 2023).

Monetary policy, driven by the *Banco Central do Brasil* (Brazil's Central Bank), has kept the Selic rate at 10.5% in mid-2024 to curb inflation currently at 4.3%. The solar PV sector is sensitive to interest rate hikes, especially in Brazil's free market environment (ACL - *Ambiente de Contratação Livre*), where short-term contracts dominate – less than 20% of energy contracted through the free market had a duration above 6 years – increasing perceived risks of these investments (Greener, 2022). Moreover, Brazil imports 99% of its solar panels (Martins & Jieqi, 2024), which are affected by currency depreciation of nearly 50% against US$ from 2013 to 2018. This has affected solar PV projects, reducing revenue from awarded Power Purchase Agreements (PPAs) by 36%, and resulting in the cancellation of several projects (IEA, 2024a).

Domestic financing through development banks, particularly the Brazilian Development Bank (BNDES), plays an important role. BNDES provided concessional, long-term debt, subsidising interest rates, when market borrowing rates were prohibitive up until 2018 (IEA, 2021). This support has been critical in a high interest rates environment driving up the cost of capital for projects. Since then, capital markets and bonds have emerged as additional financing tools, but economic policies remain important in supporting investment viability (Greener, 2022).

Solar PV Landscape

Brazil has a renewable-heavy electricity mix, which account for 86% of installed capacity (ANEEL-SIGA, 2024b, 2024a). Historically dominated by hydropower, around 65% of electricity generation, the system faces periodic droughts, exposing vulnerabilities and prompting diversification efforts, which laid the groundwork for renewable energy support mechanisms (EMBER, 2024a; Barbosa et al., 2020). The PROINFA program introduced in 2002 promoted set the precedent for the adoption of wind and biomass – but excluded solar PV initially – through long-term contracts (i.e., PPAs) and financial incentives .

Solar PV has grown rapidly (see Figure 1), adding about one gigawatt of capacity monthly between 2022 and mid-2024, accounting for 19% of installed capacity by June 2024, becoming the second largest source of electricity in the country (ANEEL-SIGA, 2024b). The expansion was supported by regulatory updates and the inclusion in the national energy auctions in 2014, critical for contracting new capacity (Viana & Ramos, 2018).

The auction system under the Regulated Contract Market (ACR) operates as a 'single buyer' model, where a central entity purchases electricity from producers (Tolmasquim et al., 2021). This allows solar developers to bid for long-term PPAs, typically 20 years, providing revenue certainty and facilitating project financing (Egli et al., 2023). Auctions have driven down utility-scale solar costs, with prices dropping from US$82-90/MWh in 2014 to US$17.6/MWh in 2019, before rebounding to US$30/MWh during the COVID-19 crisis (CCEE, 2024a; ABSOLAR, 2024). The auction market is the main study subject of this research.

The Free Contract Market (ACL) predates auctions and gained momentum in 2015 by allowing large consumers to directly contract energy from producers (Santa Catarina, 2022). Auctions, cost reductions, and regulatory changes have increased confidence in this deregulated environment, enabling consumers to choose electricity suppliers over regulated utilities (Baetas Gonçalves, 2015; CCEE, 2022).

Net metering regulations introduced in 2012 have been essential for distributed solar generation, allowing small-scale producers to feed into the grid, reducing electricity bills and improving the viability of rooftop solar (Iglesias & Vilaça, 2022; Leite et al., 2024; ABSOLAR, 2024).

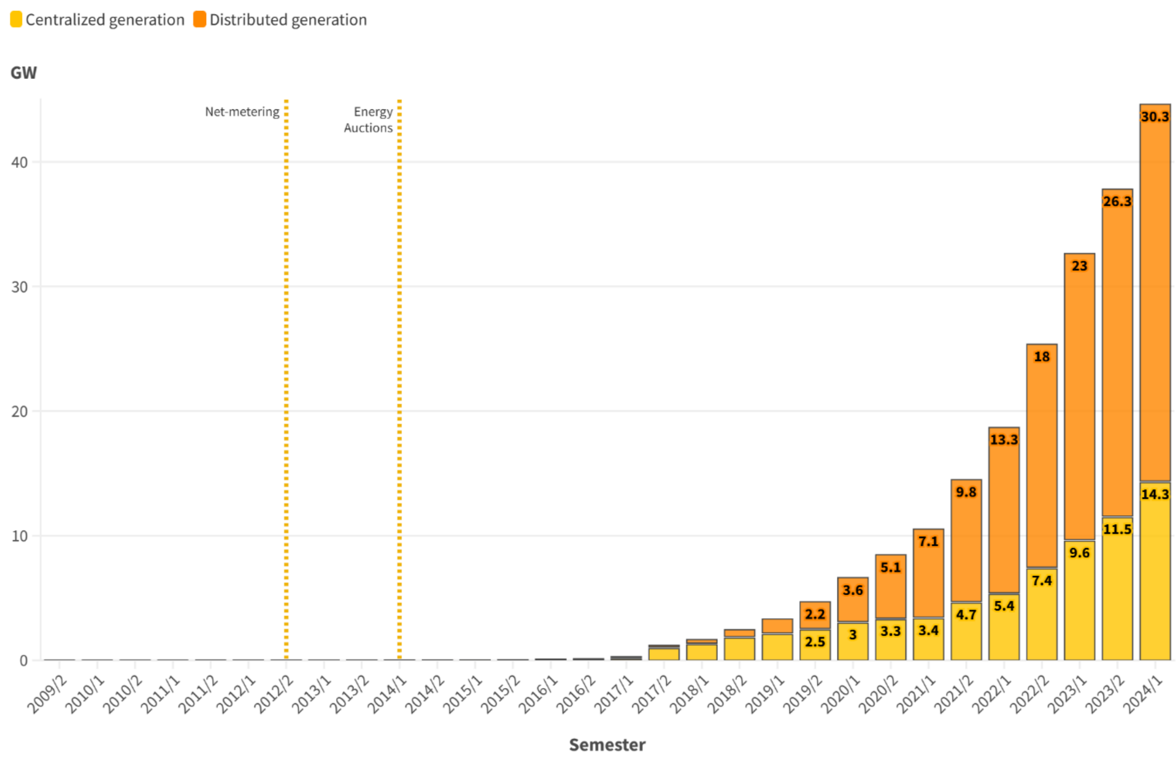

Figure 1. Solar Centralised and Distributed Generation Installed Capacity. Solar Centralised generation and Distributed generation capacity have grown exponentially in Brazil. As of June 2024, distributed generation accounts for around 70% of total solar energy capacity. Source: ANEEL-SIGA (2024a, 2024b)

The Brazilian open market has been the primary driver of solar PV development, accounting for 90% of construction volume and 64% of operating plants as of 2024 (Greener, 2024). However, the dominance of short-term PPAs in this market creates significant bankability challenges, increasing the perceived risk and cost of financing for solar projects.

BNDES role of providing subsidised interest rates and favourable loan repayment conditions for renewable projects until 2018 (BNDES, 2024b) helped developers to secure competitive financing (Silveira et al., 2024). BNDES and Banco do Nordeste remain central sources of financing, providing R$6.3 billion in 2022 (Greener, 2023). Additionally, bonds have emerged as a growing financing source. International investments now account for around half of utility-scale solar PV funding, reflecting the sector's increasing maturity (IEA, 2024a; Greener, 2022).

Brazil’s solar PV plants are concentrated in the Northeast and Southeast, regions with exceptional solar resources (i.e., capacity factors reaching 29%) and land available (see 2) (Pereira et al., 2017; Silveira et al., 2024). However, the sector faces challenges from grid integration issues, policy changes to net metering, and the introduction of import taxes on solar equipment.

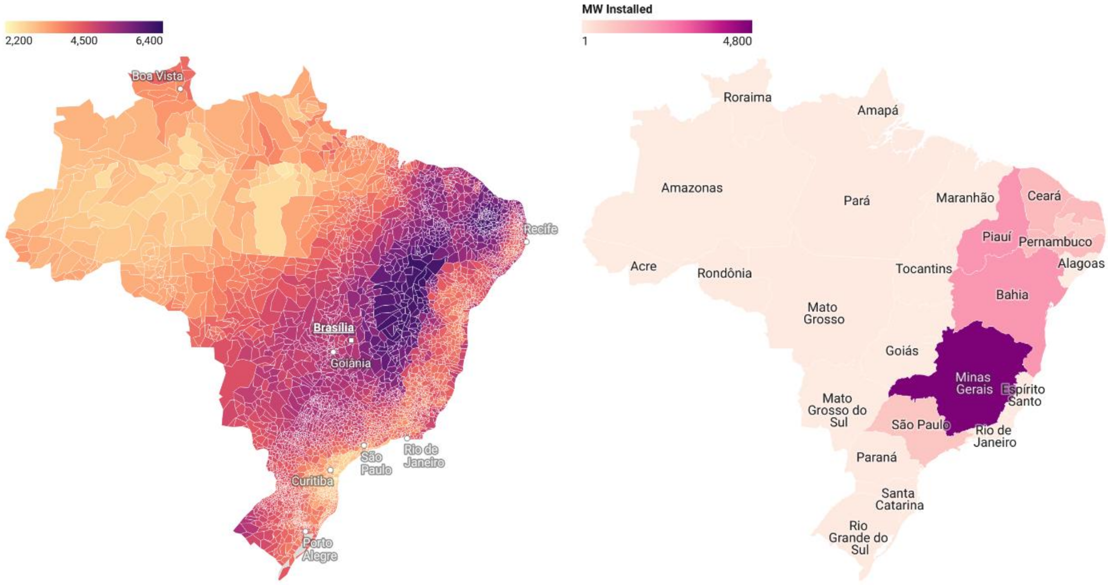

Figure 2. Utility-Scale Solar PV Installed Capacity in Brazil. Panel (a) show the solar radiation per municipality in Brazil in Wh/m^2 per day. Brazil has among the highest direct solar irradiation globally. The Northeastern region is a hotspot for solar PV projects. In panel (b) the installed capacity if shown. As of June 2024, according to (ANEEL-SIGA, 2024b) there were more than 16,000 individual projects of Solar PV in Brazil, CCEE (2024b) reports around 500 Solar PV power plants. Usually, hundreds of individual projects make up a single Solar PV power plant.

Weighted Average Cost of Capital

The weighted average cost of capital (WACC) is a critical metric for evaluating the economic viability of renewable energy projects, particularly capital-intensive technologies like utility-scale solar PV. Unlike fossil fuel-based projects with lower initial costs but ongoing fuel expenses (procurement, transportation, storage), renewable projects require significant upfront investment, making financing costs a key determinant of competitiveness (Gohdes et al., 2022; Schmidt, 2014; Schmidt et al., 2019a).

WACC acts as the project's aggregate 'interest rate,' with lower WACC rates improving investment attractiveness (Pratt & Grabowski, 2014; Steffen, 2020). It influences Levelised Cost of Energy (LCOE) which determines project feasibility (IRENA, 2023b), enabling comparisons of cost dynamics between renewable and fossil fuel investments (Chase, 2024; IRENA, 2023a; Lazard, 2024).

Globally, 88% of renewable energy projects use project finance structures, particularly for utility-scale installations (IRENA, 2023b). Using a 'Special Purpose Vehicle' isolates risk within the project without recourse to the sponsor's other assets, enabling higher debt-to-equity ratios of up to 80% in mature markets (Kann, 2009; Steffen, 2018), with debt typically cheaper than equity (Schmidt et al., 2019a). Debt financing terms, including interest rates and loan tenors, are thus critical to project viability (Egli et al., 2018). Project finance needs tailored modelling of financing costs, as applying corporate finance assumptions risks significant inaccuracies (Schmidt et al., 2019a).

Accurate data on the cost of capital for renewable energy projects is scarce due to the private nature of project finance, rapid technological advancements, and cross-country variations (Steffen, 2020; Polzin et al., 2021). Lack of transparency complicates model calibration and policymaking, as assuming a standard discount rate can lead to imprecisions (Egli et al., 2019). Researchers address these challenges through strategies like systematic reviews, auction bid analyses, and benchmarking tools calibrated with expert input (Schmidt et al., 2019a; Steffen, 2020).

The cost of capital for renewable energy projects varies widely across countries, technologies, and project characteristics. WACC ranges from 2.5% in Germany to over 10% in developing countries like Brazil, driven by country risk premiums, policy environments, and financial market maturity (Angelopoulos et al., 2016; Egli et al., 2019). Costs have declined over time, as seen in Germany's solar PV and wind projects from 2000 to 2017 (Egli et al., 2018). Project-specific factors, such as size and developer experience, also significantly influence financing costs (Steffen, 2020).

Estimating the WACC is complex due to the private nature of project finance deals. Four primary approaches address this challenge (Steffen, 2020). The most direct method involves collecting data from specific deals, as seen in Lorenzoni & Bano's (2009) surveys of Italian investors and Egli et al.'s (2018) dataset of German projects. Given data scarcity, a second approach uses expert surveys, involving interviews with market participants, exemplified by IRENA's (2023b) interviews with finance professionals and Angelopoulos et al. (2016, 2017), who used financial market data as a baseline for expert discussions.

A third method reverse-engineers winning bids from competitive auctions, leveraging publicly available non-financing data to estimate financing parameters (Apostoleris et al., 2018; Egli et al., 2023). This requires detailed auction data and realistic cost assumptions (i.e., LCOE). Finally, financial market data serves as a proxy for unlisted renewable projects, as seen in IRENA's benchmark tool (IRENA, 2023). Recent studies, including this one, combine these methods, integrating data, expert input, and market proxies for improved estimates (Egli et al., 2018; IEA, 2024a; IRENA, 2023b).

Egli et al. (2018) use after-tax WACC (equation 1), emphasising technology-specific values due to financing cost variability between technologies. Schmidt et al. (2019) use a similar approach but stress the importance of country-specific factors in calculating WACC. Uniform WACC assumptions across countries can lead to significant biases (IEA, 2021; IRENA, 2023a).

$$(1) \quad After - tax\, WACC = \delta \times (1-\tau) \times K_D + (1-\delta) \times K_E$$

The cost of capital consists of the cost of equity, cost of debt, their relative weights – the debt-equity ratio – and a tax rate (Jagannathan et al., 2016). Steffen (2020) notes the after-tax WACC is most common due to tax-deductible interest payments and assumes a tax shield discounted at the cost of debt, which may not always be accurate.

Cost of debt is determinant for the WACC, as highly leveraged renewable projects with significant upfront costs mostly rely on debt financing (Steffen, 2018). However, Steffen (2020) notes that the cost of debt is often not directly observable as finance deals are privileged information, thus researchers rely on expert estimates or derived market values.

Various methods estimate the cost of debt. Steffen (2020) notes that for listed companies, it is available through current interest expenses or bond yields. Egli et al. (2023) estimate it for solar PV projects by deriving it from auction prices reflecting the Levelised Cost of Electricity (LCOE), using project-specific capital and operational costs. Partridge (2018) determines it by adding a risk premium to long-term government bond rates, adjusting for tax benefits, and slightly increasing the rate for renewable projects due to higher perceived risks.

(IRENA, 2023b) calculates the cost of debt across regions by combining the global risk-free rate (GFR), country-specific default spread (CDS), lender margin (LM), and a technology premium (TP), adjusted for tax to reflect the actual project cost, yielding equation 2:

$$(2) \quad K_D = GFR + CDS + LM + TP$$

Kitzing & Weber (2014) estimate the cost of debt for wind power projects in Germany using an equation that combines the risk-free rate (RF), a credit spread (P_{swap}), and an additional bank margin (BM), assessing borrowing costs specific to the German wind energy sector:

$$(3) \quad K_D = RF + P_{swap} + BM$$

Egli et al. (2018) estimate the cost of debt for solar PV and onshore wind in Germany by analysing debt margins (DM), added to the risk-free rate (RF) to compensate for specific project risks. In Brazil, BNDES charges a 1.1% premium for solar PV projects (BNDES, 2024a). The debt margin decreases as cumulative investments grow, reflecting reduced lender-perceived risk over time:

$$(4) \quad K_D = RF + DM$$

Angelopoulos et al. (2016) calculate the cost of debt for onshore wind investments in EU countries using the European risk-free rate (RF), country-specific credit default spread (CDS), and a project-specific spread (PS), capturing country-specific risks and project uncertainties across EU states:

$$(5) \quad K_D = RF + CDS + PS$$

The cost of equity represents the return required by equity investors and is typically harder to estimate than the cost of debt due to its implicit nature. Steffen (2020) identifies the Capital Asset Pricing Model (CAPM) as the most common method for estimating it:

$$(6) \quad K_E = RF + \beta \times (MRP - RF)$$

However, CAPM's application to renewable projects, especially in emerging markets, has been questioned. Donovan and Nuñez (2012) propose a 'downside beta CAPM' to address non-normal return distributions, emphasising context-specific approaches.

IRENA's (2023b) cost of equity calculation incorporates country risk adjustments using Damodaran's data on risk premiums and default spreads, refining the global risk-free rate to account for specific country risks, ensuring accurate WACC estimates for renewable projects:

$$(7) \quad K_E = RF + ERP + CP + TP$$

Schmidt et al. (2019) build the cost of equity on the cost of debt, adding a premium to compensate for higher equity investor risk. The equity premium is added to the risk-free rate and debt margin to reflect higher return expectations:

$$(8) \quad K_E = RF + DM + ERP$$

WACC for renewable energy projects is shaped by macroeconomic factors such as country risk, interest rates, and financial market maturity. Country risk premiums significantly impact financing costs, with WACC varying from 2.2% in Germany to 12.2% in Ukraine (IRENA, 2023b). Rising interest rates complicate financing, with substantial increases in LCOE for solar PV and onshore wind under pre-financial crisis rate conditions (Aguila & Wullweber, 2024; Schmidt et al., 2019). The end of the 'zero era' for interest rates amplifies these challenges, with contractionary monetary policies disproportionately affecting capital-intensive renewable projects and potentially delaying the energy transition (Martin et al., 2024).

Steffen & Waidelich (2022) framework emphasises the influence of market design, renewable energy policies, and financial sector maturity on financing costs. Renewable energy auctions and stable regulatory environments can reduce perceived risk (Polzin et al., 2021). Project finance structures, characterised by high debt shares, increase sensitivity to interest rate fluctuations, particularly for low-carbon technologies (Martin et al., 2024; Steffen, 2018). This underscores the importance of integrating differentiated costs of capital into energy models and policy planning while exploring roles for central banks in supporting renewable energy financing through targeted credit policies or monetary interventions (Aguila & Wullweber, 2024; Schmidt et al., 2019).

Methodology

The research assesses the influence of financing conditions on the Levelised Cost of Energy (LCOE) for solar PV projects in Brazil. The research employs a three-tiered methodological approach, with each stage building on insights from the previous one (see Figure 3). The analysis was conducted using Python in Jupyter Notebooks. All relevant data and code are available in the Zenodo repository https://doi.org/10.5281/zenodo.14529054.

Level 1 estimates the nominal after-tax WACC for solar PV projects in Brazil, establishing a clear estimate of financing costs. Level 2 calculates the LCOE for solar PV projects that won energy auctions in Brazil between 2014 and 2022, evaluating how financing costs have evolved. Level 3 constructs economic projection scenarios for general interest rates and inflation in Brazil, exploring how anticipated changes in these factors from 2024 to 2029 could impact the WACC and LCOE for solar PV projects.

This approach provides a comprehensive assessment of past and current financing conditions affecting solar PV projects in Brazil, offering valuable insights on costs and future projections (see Annex 2 for more description).

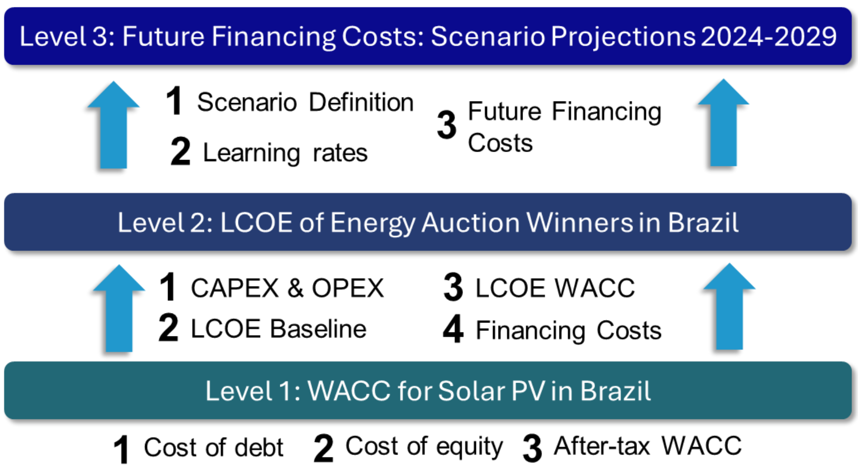

Figure 3. Three-tiered Methodological Approach.

Level 1: WACC for solar PV in Brazil

The calculation of the WACC is critical for investors in evaluating the financial viability of solar PV projects in Brazil. As a key determinant of the LCOE, the WACC is essential for comparing energy generation costs across various sources (IEA, 2023; IRENA, 2023b).

This analysis calculates the WACC within Brazil's unique macroeconomic environment. A thorough examination of debt and equity components, particularly the influence of fluctuating interest rates and inflation, was conducted. The methodology draws on the IRENA report (2023b) and Egli et al. (2018), with adaptations to suit the Brazilian context. To ensure robustness, various methodological approaches were considered, including Schmidt et al. (2019), Santa Catarina (2022), and Damodaran (2024), allowing for a comprehensive analysis tailored to the Brazilian renewable energy market. Cost of debt calculation is the first step in determining the WACC. Using the IRENA methodology as a base, the cost of debt (K_D) is calculated with equation (2). Note this equation includes the tax shield already and is thus not be applied to equation again (1):

$$K_D = (GRF + CDS + LM + TP) \times (1 - \tau)$$

In IRENA's report, GRF represents the Global Risk-Free rate (10-year US Treasury bond yield). The Country Default Spread (CDS) is the spread between the 10-year US Treasury bond and a US$-denominated sovereign bond of the same duration. The Lender Margin (LM) is the premium added by lenders for infrastructure projects. The Technology Premium (TP) accounts for the additional risk associated with solar PV and τ represents the corporate tax rate.

Applying this methodology to Brazil presents challenges. A US$-denominated bond yield for Brazil's risk-free rate gave an unrealistically low cost of debt, failing to capture local risks like inflation, currency, and economic volatility. Conversely, a BRL-denominated 10-year government bond yield yielded an excessively high cost of debt, as Brazil's lending rates remained subsidised until recently. To address these issues, the cost of debt calculation was based on NTN-B bond yields, Brazilian government bonds providing a real return above inflation (see Figure A14). NTN-B yields were chosen due to their strong correlation with the 10-year government bond yield and the Selic Target rate. Additionally, BNDES, the primary financier of Brazil's solar PV projects, has linked rates to NTN-B yields since introducing the *Taxa de Longo Prazo* (TLP, Long-term rate) in 2018 (BNDES, 2024c).

The long-term rate (TLP) is a nominal rate comprising a real interest rate, derived from five-year NTN-B bond yields, and an inflation adjustment. It is calculated using the average of NTN-B yields from the past three months plus the previous monthly year-on-year inflation. An adjustment factor was applied to the NTN-B bond's real interest rate as lending rates gradually reflected the open market state, but since 2023, no adjustment factor is used. Historical NTN-B yield data were collected from LSEG (2024), and a moving average adjusted by the BNDES factor was calculated and compared with historical BNDES rates for future projections in Level 3 (BNDES, 2024c).

Observed long-term rates (TLP, introduced in 2018, Figure A17) were merged with historical TJLP rates, adjusting the latter for inflation to align with the TLP. The TJLP, a subsidised rate, included an inflation target, requiring an IPCA adjustment. The final cost of debt calculation incorporated the BNDES rate, adjusted for inflation, as the Brazilian risk-free bond yield.

The CDS was calculated by subtracting US Treasury bond yields from the BNDES rates. No Lender Margin was added as the BNDES rate already applies to infrastructure projects. The Technology Premium was calculated based on the percentage of installed solar capacity relative to Brazil's total installed capacity, reflecting technological maturity, which is common practice (IRENA, 2023b). The study used three market maturity buckets: 'New Market' (< 5%), 'Intermediate Market' (5%-10%), and 'Mature Market' (≥10%). For each bucket, the premium decreases linearly or remains fixed from 10% onwards, with linear interpolation for exact percentages.

As of August 2024, BNDES Finem – a type of financing for big infrastructure projects – charges 1.1% as a remuneration rate for solar technology, aligning with this approach. The higher premium (1.5%) reflects that commercial banks may offer less competitive rates than BNDES (BNDES, 2024a).

The total cost of debt for Brazil adds all variables and is then reduced by applying the 34% corporate tax rate to account for tax-deductible interest payments $(1 - \tau)$. This approach provides a realistic estimate of the cost of debt for subsequent calculations. The cost of equity, an essential component in the WACC calculation, is determined using the equation (7). Note that GRF equals RF in equation (7), but GRF is adapted within our methodological framework:

$$K_E = GRF + CP + ERP + TP$$

In this equation, the GRF is represented by the yield on 10-year US Treasury bonds. The Equity Risk Premium (ERP), as calculated by Damodaran (2024), reflects the mature market equity risk and is based on the premium of US sovereign bonds adjusted by the volatility of the S&P 500. Damodaran's ERP values were linearly interpolated to obtain a monthly cost of equity over the study period.

The Country Premium (CP) component accounts for the additional risk specific to the Brazilian market. Rather than following IRENA's methodology using Damodaran's estimations, the Country Premium was derived from the country default spread used for the cost of debt (CDS), calculated as the difference between Brazil's bond yields, reflected in the BNDES rate, and the global risk-free rate. This ties the country premium to local interest rates, aligning with the focus on understanding how interest rates influence the cost of capital in Brazil.

This approach resonates with energy finance literature, such as Donovan & Nuñez (2012) and Schmidt et al. (2019), where the cost of equity is defined as the cost of debt plus an equity premium. The Technology Premium (TP) component, previously calculated, is added to this equation.

The harmonisation of the WACC components, as proposed by IRENA and Schmidt et al. (2019) ensures analytical consistency. Using the BNDES rate and BRL bond yields to estimate both debt and equity costs reflects Brazil's unique financial environment, where BNDES is pivotal. This approach also accounts for local interest rates and currency risks, key to solar PV project viability.

By adopting this methodology, the analysis maintains coherence and relevance, particularly when projecting how interest rate fluctuations impact solar PV project capital costs in Brazil. Integrating these components into the WACC equation provides a comprehensive financial view, essential for LCOE calculations. After estimating both the cost of debt and the cost of equity, leverage of solar PV projects was determined based on market maturity, measured by installed solar capacity as a percentage of total electricity capacity. Using IRENA's approach, three market maturity buckets were assigned fixed debt shares: 80% for 'Mature Market' (≥10%), 70% for 'Intermediate Market' (5%-10%), and 60% for 'New Market' (< 5%). This ensures debt financing reflects the relative risk of market maturity, with greater debt proportions as markets mature.

With these debt shares established, the nominal after-tax WACC was calculated using equation (1):

$$WACC = \delta \times (1 - \tau) \times K_D + (1 - \delta) \times K_E$$

In this equation, K_D represents the cost of debt, K_E is the cost of equity, δ is the leverage (or debt share), and τ is the corporate tax rate. This calculation integrates the respective costs of debt and equity, weighted by the project's leverage, and adjusts for the tax deductibility of interest payments. The result is a comprehensive measure of the overall cost of capital.

Level 2: LCOE of Energy Auction Winners in Brazil

The second stage calculates the LCOE for solar PV projects that secured contracts in Brazil´s energy auctions from 2014 and 2022, focusing on the evolution of financing costs using the

WACC from Level 1. The analysis follows methodologies employed by Egli et al. (2018) and Schmidt et al. (2019) in their study of renewable energy projects in Germany.

Data was sourced from the Chamber of Electric Energy Commercialization (CCEE), which provides details on winning projects from energy auctions since 2004 (Tolmasquim et al., 2021; CCEE, 2024). Key variables for LCOE calculations included auction date, seller name, investment amount, nominal capacity, and physical guarantee of individual projects.

This methodology draws on Santa Catarina (2022), who calculated LCOE for 758 Brazilian wind projects, and Egli et al. (2018), who analysed the impact of financing conditions on renewable energy costs.

Our analysis included 195 solar PV projects from energy auctions (2014-2022), excluding two that participated in a specific auction type called the Simplified Competitive Procedure. Most projects originated from reserve and alternative power auctions, with contracts lasting 20 years (reduced to 15 years since 2021). Afterward, agreements can be renegotiated in either the regulated (ACR) or open (ACL) markets.

The LCOE calculation considers inputs like taxes, operating costs (OPEX), inflation assumptions, and WACC. Unlike Santa Catarina (2022), who included federal taxes directly in the LCOE, this analysis integrates them into the after-tax WACC (see level 1), while Santa Catarina used a before-tax WACC from Brazil's Energy Research Company (EPE).

Following Santa Catarina (2022) the declared investment amounts from auctions were used as the project CAPEX. Annual energy production was estimated by multiplying the capacity factor, nominal capacity in MW and total yearly hours. This calculation provided the expected annual energy production in MWh.[1] OPEX was calculated as 1.45% of project CAPEX, based on De Jong et al. (2015) who estimated OPEX as 1% of the investment projects of onshore wind. The 1.45% percentage was derived from data provided by the Empresa de Pesquisa Energética (EPE), providing a consistent method for estimating annual OPEX across all projects. OPEX was adjusted for inflation over the project lifetime, using a compounded annual inflation rate of 3.5%:

$$(9) \quad OPEX_t = OPEX_{initial} \times (1 + inflation\ rate)^t$$

Based on Egli et al. (2018), the analysis established a baseline by calculating an LCOE excluding financing costs (0% WACC). This approach isolates the CAPEX and OPEX components over the

[1] $Expected\ energy\ production\ =\ Capacity\ factor\ \times Nominal\ capacity\ \times 8{,}760$

25-year project lifetime (Ministério de Minas e Energia (MME) & EPE, 2022). The baseline LCOE was calculated using the following equation:

$$(10) \quad LCOE_{it,WACC=0} = \frac{C_{it}}{\sum_{t=1}^{25} FLH_{it\tau}} + \frac{\sum_{t=1}^{25} C_{it\tau}}{\sum_{t=1}^{25} FLH_{it\tau}}$$

This approach provided a nominal LCOE value, representing energy production costs without financing impacts.

To include financing costs, the LCOE was recalculated using the project-specific WACC from Level 1. This required discounting both OPEX and expected energy production over the 25-year project lifetime. Each year's OPEX and energy production were discounted to present value using the WACC corresponding to the month preceding the auction, assuming financing terms were set beforehand. This ensured consistency across all financial modelling aspects of the project:

$$(11) \quad LCOE_{WACC} = \frac{C_{it}}{\sum_{t=1}^{t=25} \frac{FLH_{it\tau}}{(1+WACC_{it})^{\tau}}} + \frac{+\sum_{t=1}^{t=25} \frac{C_{it\tau}}{(1+WACC)^{\tau}}}{\sum_{t=1}^{t=25} \frac{FLH_{it\tau}}{(1+WACC)^{\tau}}}$$

The impact of financing costs is quantified by calculating the financing expenditure (δ_{it}), the difference between the LCOE with observed WACC and the baseline LCOE:

$$(12) \quad \delta_{it} = LCOE_{it} - LCOE_{it,WACC=0}$$

The change in financing costs over time (Δ_i) is assessed by comparing the financing expenditures across years:

$$(13) \quad \Delta_i = \delta_{it=1} - \delta_{it=2}$$

These calculations isolate financing's impact on LCOE, clarifying how financing conditions have shaped solar PV project costs over time.

Level 3: Future Financing Costs: Scenario Projections 2024-2029

This stage projects future financing conditions and their impact on LCOE for solar PV projects in Brazil from 2024 to 2029, focusing on how macroeconomic variables, particularly bond yields and inflation, affect financing costs. The approach is based on methodologies from Schmidt et al. (2019) and Egli et al. (2018), adapted to Brazil's economic context.

The analysis utilised a dataset from LSEG (2024), covering monthly yields of 5-year NTN-B bonds, 10-year government bond yields (BR10YT), and year-on-year inflation changes from

October 2017 to June 2024. Augmented Dickey-Fuller (ADF) tests confirmed the data was non-stationary, requiring differencing to achieve stationarity. Subsequent ADF tests validated the transformation for regression analysis.

Regression analysis on the differenced series revealed a strong relationship between the 10-year government bond yield and the 5-year NTN-B yield, with a 1 percentage point increase in the former raising the latter by 0.43 percentage points. This relationship guided NTN-B yield projections under three scenarios: a flat scenario with bond yields stable at the 2024 average of 11.40%; a downward scenario with yields dropping to the 2020 low of 6.3%; and an upward scenario with yields peaking at the 2015 high of 16.49%.

Recognising the link between inflation and interest rates in Brazil's volatile economy, dynamic inflation rates were applied to each scenario. In the flat scenario, inflation stays at 4.4%, reflecting recent trends. In the upward scenario, inflation to 6.3% by 2029, aligning with rising interest rates, while in the downward scenario, inflation falls to 3.4% by 2029, suggesting economic stability and lower bond yields.

To calculate the WACC across scenarios, the average NTN-B yield from January to June 2024 served as a starting point. A technology premium of 1.5%, equity risk premium of 4.27%, leverage of 80%, and a tax rate of 34% were held constant. NTN-B yield projections for each scenario (July 2024-December 2029) were used to calculate yearly averages from 2025 to 2029.

Future CAPEX values were projected using a learning curve approach, which models cost reductions with cumulative installed capacity (Schmidt et al., 2019). A 15% learning rate was applied, meaning costs decrease by 15% with each capacity doubling. Baseline CAPEX, based on 2022 solar auction projects in Brazil, was BRL 167,735,285.6 per 40 MW. Projections utilised global capacity data (2023-2029) from IRENA and IEA reports, reflecting expected reductions from technological advancements and economies of scale.

The nominal OPEX for 2022 was BRL 2,430,484.288 per year, or 1.449% of CAPEX for that year. A conservative OPEX learning rate of 5% per capacity doubling, based on learning-by-doing, economies of scale, and innovation, was applied (Steffen, 2020). OPEX was adjusted for an average inflation rate of 4% to reflect evolving economic conditions (MercoPress, 2024).

Maintaining a constant 4% inflation rate for long-term LCOE calculations, while varying it for WACC scenarios, ensures that LCOE comparisons focus solely on financing impacts. This consistent approach avoids introducing variability from inflation assumptions, enabling a clear analysis of how macroeconomic conditions influence the economic viability of solar PV projects. By integrating these dynamic elements, this methodology offers a nuanced understanding of the financial factors shaping solar PV projects over the next five years.

The LCOE was recalculated annually for each scenario, incorporating dynamically adjusted CAPEX, OPEX, and WACC values. The BNDES rate, a key WACC component, was updated starting from October 2023 by averaging the prior three months' NTN-B yield and adding the inflation rate for the latest month. This ensured that the WACC reflected current economic data and macroeconomic conditions. The established methodology was applied integrating scenario-specific variables.

The LCOE was broken into OPEX baseline, CAPEX baseline, and financing costs. Financing costs were isolated by subtracting the LCOE baseline (0% WACC) from the LCOE calculated with the respective WACC. The OPEX baseline and expected energy production were derived as in Level 2, showing OPEX's contribution to the LCOE without the WACC's impact. The CAPEX baseline represented the LCOE portion from initial capital expenditure, distributed across the project's total lifetime energy production.

Financing costs were determined by subtracting the LCOE baseline (0% WACC) from the LCOE calculated with the respective WACC, isolating the financing impact on the energy production costs. For each scenario (Flat, Upward, Downward), this calculation revealed the additional cost incurred due to financing under varying economic conditions.

These steps were integrated to finalise LCOE calculations for each scenario. By breaking down the LCOE into OPEX, CAPEX, and financing costs, the analysis provided a clear understanding of how different economic conditions affect the overall cost of solar PV energy production.

Limitations

This research provides valuable insights but has several limitations. It relies on publicly available data from energy auctions, which may not reflect the complexities of private financing or bilateral contracts in Brazil's solar market. Projections for future financing conditions are based on historical trends, which may fail to anticipate sudden political or economic shifts in Brazil. Additionally, while Brazil boasts some of the highest solar irradiation globally, capacity factors calculated using Santa Catarina (2022) methodology appear unusually high. Although achievable in select locations, a lower average capacity factor might yield more generalisable results. The methodology assumes continuity in financing cost trends, potentially overlooking disruptive events or innovations in financial markets. Furthermore, while the study thoroughly analyses WACC and LCOE, it does not address all risks associated with project development, such as land acquisition, grid connection delays, or regulatory changes, which could also significantly affect project costs.

Discussion and Results

The analysis on Level 1 of cost of equity and debt for Brazilian solar PV projects from 2014 to 2024 reveals a complex interplay of macroeconomic factors, policy shifts, and technological maturation. The sharp increases in financing costs from 2020 to 2022 directly reflect Brazil's economic challenges during the COVID-19 pandemic, including GDP contraction, currency depreciation, and inflationary pressures. This period of instability, leading to significant monetary tightening by Brazil’s Central Bank supports Schmidt et al.'s (2019) framework on the rapid impact of interest rate fluctuations on renewable energy financing in emerging markets.

A critical juncture in the cost of debt trend occurred around 2018, coinciding with the transition from TJLP, the subsidised rate, to TLP, the open market rate. This shift toward market-based long-term interest rates for BNDES financing underscores the significant impact of policy changes on renewable energy financing, a theme emphasised by Polzin et al. (2021). The clear break in trends before and after this transition suggests that while it increased short-term volatility in financing costs, it has also fostered a more transparent and market-responsive financing environment.

The heightened volatility in both cost of equity and debt, particularly after 2020, aligns with Steffen's (2020) findings on the role of country-specific risk factors in renewable project financing. Significant fluctuations in the Country Default Spread, especially during periods of economic uncertainty, highlight Brazil's unique risk profile as an emerging market. This volatility underscores the challenges renewable energy investors face, where macroeconomic instability can quickly undermine project viability.

The gradual decline in the technology premium for solar PV over the studied period supports Egli et al.’s (2018) concept of ‘financing experience effects’. This trend aligns with Brazil's rapid solar PV capacity expansion, likely increasing investor familiarity and reducing perceived technological risks.

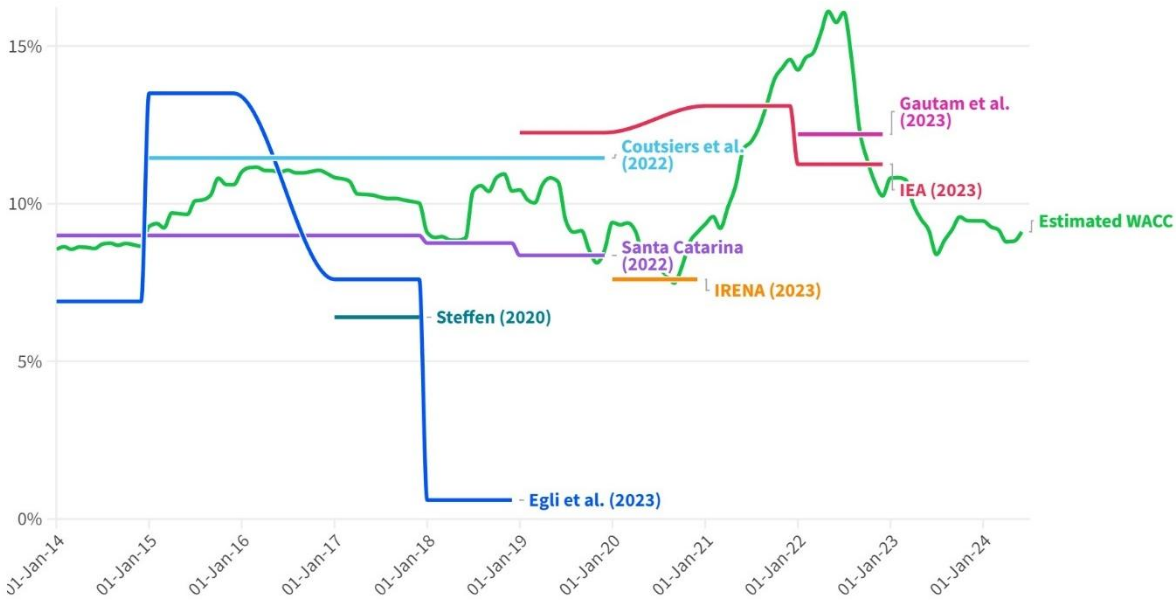

Figure 4. Granularity: Estimated WACC vs. Literature WACC. Egli et al. (2023) recognise their estimations are unreliable. Coutsiers et al. (2022) estimate a 2015-2019 average. Santa Catarina ***(2022)*** *uses a non-technology specific EPE renewable energy estimated after-tax WACC (average from 2014-2017). Gautam et al. (2023) do not specify if their methodology is after or before taxes, plus, they innovate the cost of capital methodology through a regression between the WACC and a Climate Risk Score, nevertheless, those final values are not publicly available.*

The comparison of WACC estimates with existing literature reveals significant disparities, highlighting the difficulties in assessing financing costs for solar PV projects in emerging markets like Brazil. The stark contrast between this study's estimates and those of Egli et al. (2023) underscores the limitations of applying methodologies developed for mature markets to emerging economies.

The more stable WACC estimates from Coutsiers et al. (2022) and Santa Catarina (2022) differ from the volatility observed in this study, likely due to their use of averaged values over longer periods, which smooth short-term fluctuations. In contrast, the higher WACC values reported by IEA (2023) and Gautam et al. (2023) align more closely with this study's estimates, suggesting that recent assessments better capture evolving risk perceptions in the Brazilian market.

The variation in WACC estimates across studies highlights the complexity of assessing the cost of capital for renewable energy projects in emerging markets. Methodological differences, data sources, and time frames can produce divergent results. This study's estimates, which are more sensitive to short-term economic fluctuations, offer a nuanced perspective on changing risk perceptions in Brazil’s solar PV market.

The analysis of solar PV projects winning Brazil's energy auctions in Level 2 reveals several trends shaped by both global developments and Brazil-specific factors.

The capacity awarded in auctions fluctuated significantly, peaking at 1.8 GW in 2015 before declining to 0.4 GW in 2022. This pattern likely reflects shifting policy priorities and market conditions, as noted by Tolmasquim et al. (2021) in their analysis of Brazil's electricity sector reforms. Notably, this marks a clear shift from the regulated market to the open market. By 2018, 100% of accumulated capacity was under regulated auctions, but developers appear to prefer bilateral negotiations, likely due to more favourable conditions (Greener, 2024). The last energy auctions for solar were in 2022.

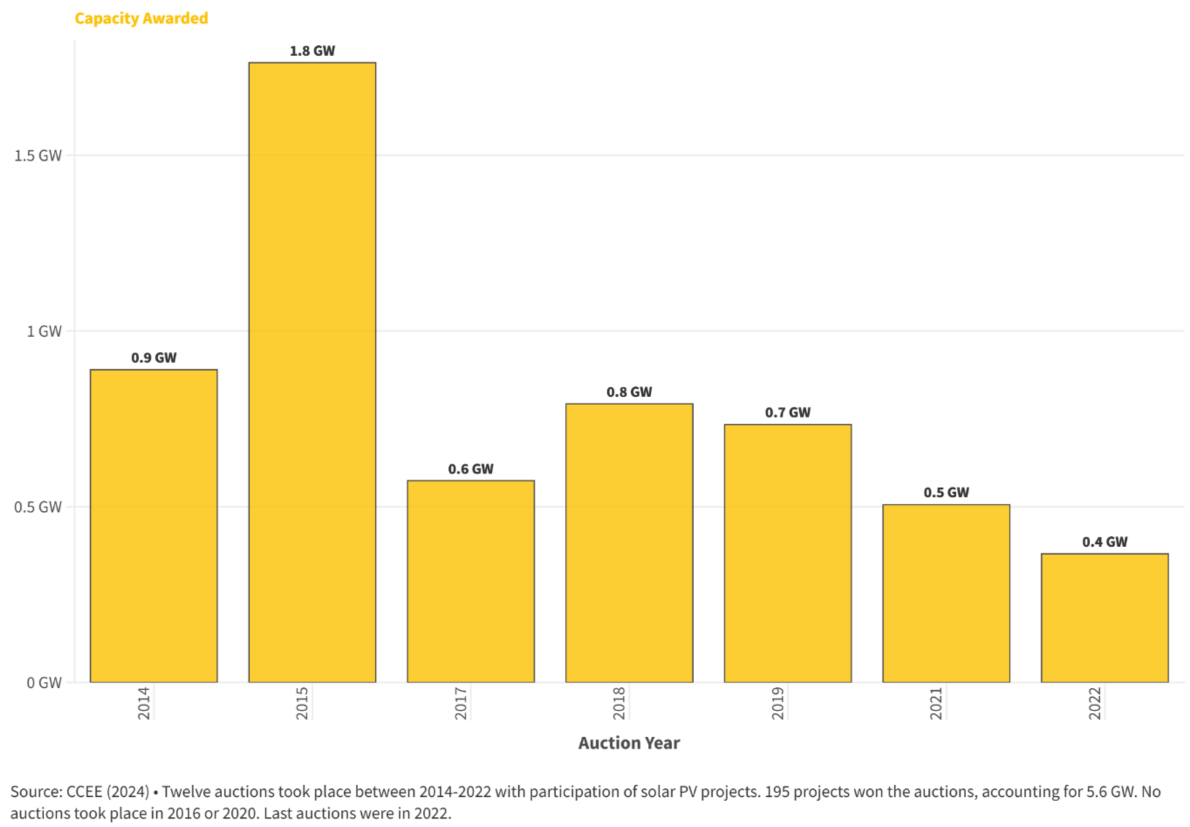

Figure 5. Solar PV Capacity Awarded in Energy Auctions in Brazil. Twelve auctions took place between 2014-2022 with participation of solar PV projects. 195 projects won the auctions, accounting for 5.6 GW. No auctions took place in 2016 or 2020. Last auctions were in 2022. Source: CCEE (2024)

CAPEX for Brazilian solar PV projects (Figure A18) shows a clear downward trend, closely aligning with IRENA's global weighted average. This trend supports Nemet's (2019) observations on cost reductions driven by technological advancements and learning effects in project development and construction. Solar panels costs have consistently declined (EMBER, 2024b). Notably, Brazil's CAPEX remains below IRENA's 95th percentile (Figure A18), reflecting effective cost management within the competitive auction system.

Auction sale prices (Figure 6) fell sharply from US$88/MWh in 2014 to US$17.6/MWh in 2019, followed by a slight uptick. This trend aligns with Dobrotkova et al. (2018)) findings on price declines in emerging market solar auctions. The data reveals an interesting dynamic: while CAPEX steadily decline, auction prices exhibited more volatility after 2019. This divergence supports Egli et al.'s (2018) assertion that financing costs play a crucial role in determining LCOE for capital-intensive technologies like solar PV.

The volatility in auction prices could reflect increasing merchant risk exposure, as noted by IRENA (2023b). Developers may be pricing in higher risk premiums tied to Brazil's macroeconomic challenges and policy uncertainties discussed earlier. This highlights the need for a holistic approach to analysing renewable energy markets in emerging economies, accounting for both technological advancements and broader economic and policy factors.

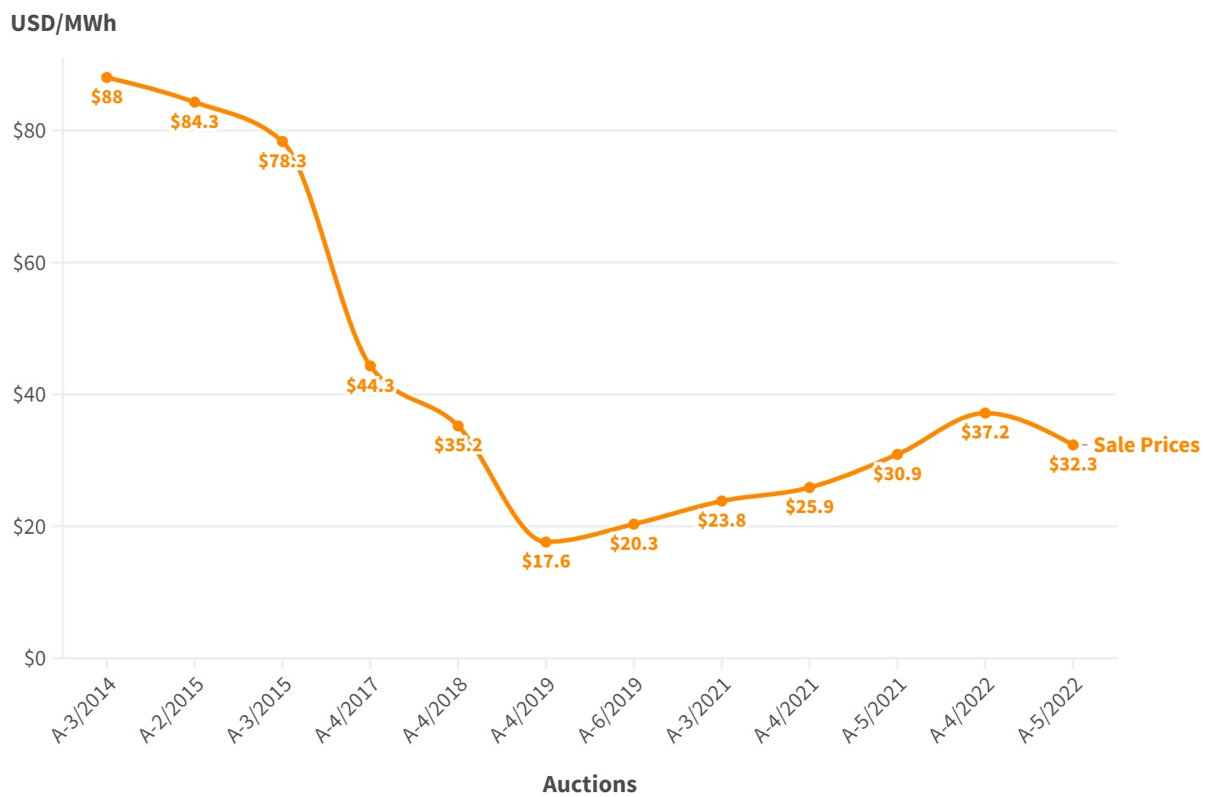

Figure 6. Solar PV Sale US$ Prices in Brazil's Energy Auctions. Data source: CCEE (2024a)

The capacity factor (Figure A19) shows an increasing trend for Brazilian projects, surpassing IRENA's global weighted average. This improvement likely reflects advancements in solar technology or suggests projects are being developed in increasingly optimal locations, which may involve higher land acquisition or grid connection costs not captured in CAPEX figures (Klingler et al., 2023). The data highlights the need to consider country-specific factors, such as financing costs and macroeconomic conditions, when assessing renewable energy competitiveness, as emphasised by Schmidt et al. (2019).

The analysis of LCOE for solar PV projects in Brazil from 2014 to 2022, presented in both Brazilian Reais (BRL) and US Dollars (US$), provides crucial insights into the evolving economics of solar energy in the country.

The LCOE trend in nominal BRL (Figure 7) shows an initial decline followed by an uptick from 2018 to 2022. This pattern aligns with Brazil’s macroeconomic challenges, particularly economic instability during the COVID-19 pandemic and subsequent monetary tightening. As Martin et al. (2024) noted, the end of the 'zero era' for interest rates has significant implications for the energy transition, reflected in the rising BRL LCOE.

In contrast, the LCOE in US$ shows a consistent downward trend, mirroring global solar PV cost reductions. This BRL-US$ divergence highlights the impact of currency fluctuations on project economics, a risk compounded by Brazil’s reliance on imports for up to 99% of its solar panels (Martins & Jieqi, 2024).

Compared to IRENA global averages, Brazilian LCOEs have generally tracked below global levels since 2016. This indicates that despite macroeconomic challenges, Brazil retains a competitive edge in solar PV deployment, possibly due to its favourable solar resources and competitive auction system, as discussed in the solar PV landscape section.

The widening LCOE ranges in recent years indicate growing project heterogeneity, likely due to increased diversity in project sizes, locations, and the shift towards the ACL (Greener, 2024). These findings have significant implications for policymakers and investors. For policymakers, the rising LCOE in BRL terms highlights the need for measures to mitigate macroeconomic volatility, such as supporting local manufacturing or introducing innovative financial instruments to hedge against currency risks.

For investors, the divergence between BRL and US$ trends creates a complex decision-making environment. Those with access to BRL financing benefit from inflation-indexed auction contracts, providing a natural hedge against local inflation, though BRL volatility increases perceived risk. Conversely, investors using US$ financing may enjoy more stable returns in US$ terms but face considerable currency risk.

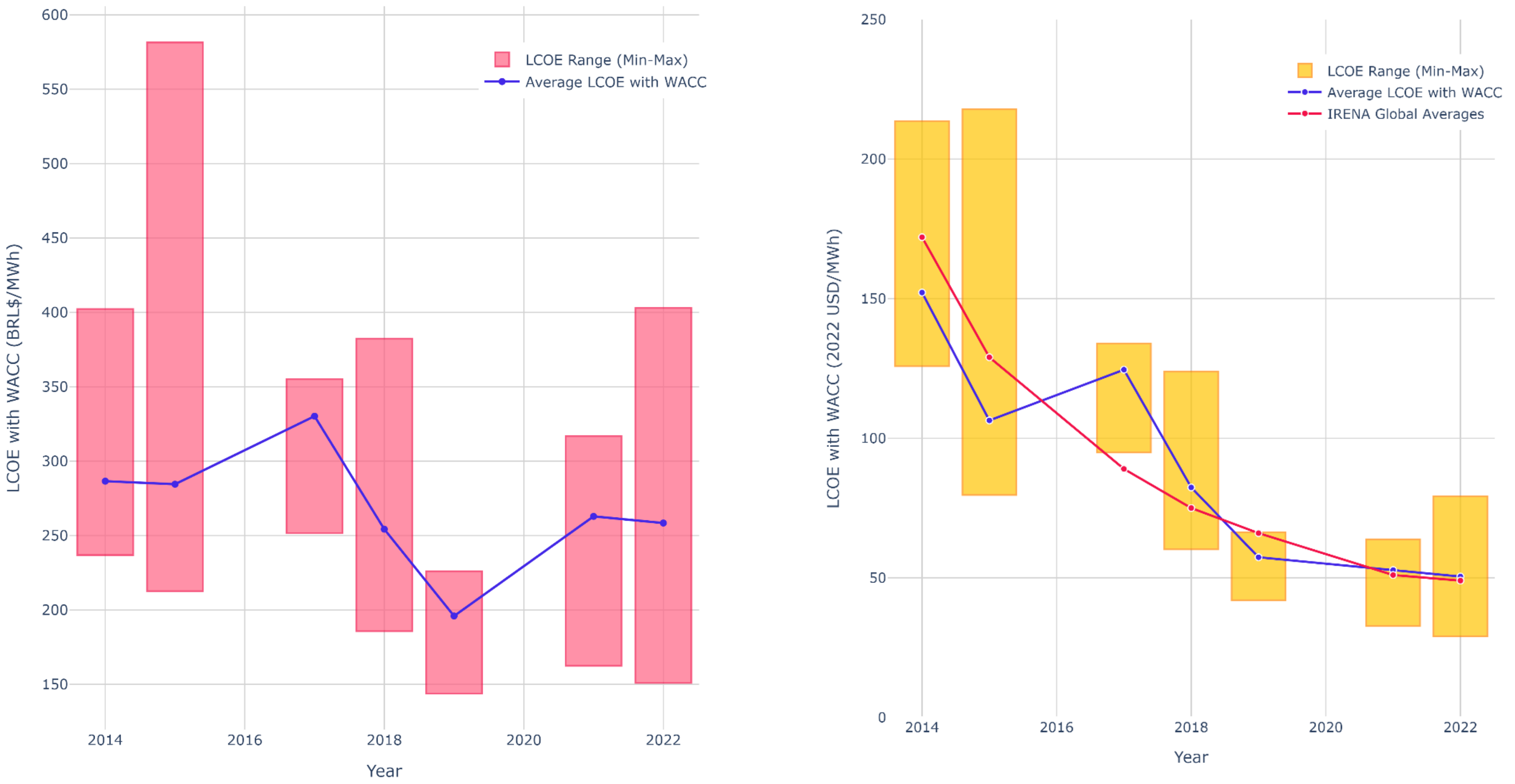

Figure 7. LCOE with WACC from 2014 to 2022 in nominal BRL values (pink graph) and adjusted for inflation in 2022 US$ vs. IRENA (yellow graph)

The results of financing costs for solar PV projects in Brazil from 2014 to 2022 also provides critical insights into the evolving economics of renewable energy in emerging markets. The waterfall chart in Figure A20 illustrates the methodology used to isolate financing costs, like the approach employed by Schmidt et al. (2019) and Egli et al. (2018). This decomposition of LCOE into CAPEX, OPEX, and financing components allows for a nuanced understanding of the factors driving changes in the overall cost of solar electricity generation.

The comparison between 2014 and 2022 in Figure 8 reveals a complex evolution of cost components. The CAPEX reduction from R$96/MWh to R$62/MWh aligns with the global trend of declining solar PV equipment costs noted in the literature review section. Similarly, the OPEX reduction from R$56/MWh to R$36/MWh reflects improvements in operational efficiency and maintenance practices, consistent with the learning effects and economies of scale observed in maturing solar markets worldwide (Nemet, 2019; Steffen, 2020).

However, the most striking finding is the increase in financing costs from R$135/MWh to R$160/MWh, an 18.5% rise. This trend aligns with the findings of Schmidt et al. (2019), who emphasised the critical role of financing costs in determining the overall competitiveness of renewable energy in emerging markets. The increase in financing costs, despite reductions in CAPEX and OPEX, can be attributed to several factors discussed in the Brazilian context section, including macroeconomic volatility, policy changes (such as the transition from the subsidised rate to the unsubsidised one), and the complex interplay between market maturity and broader economic challenges.

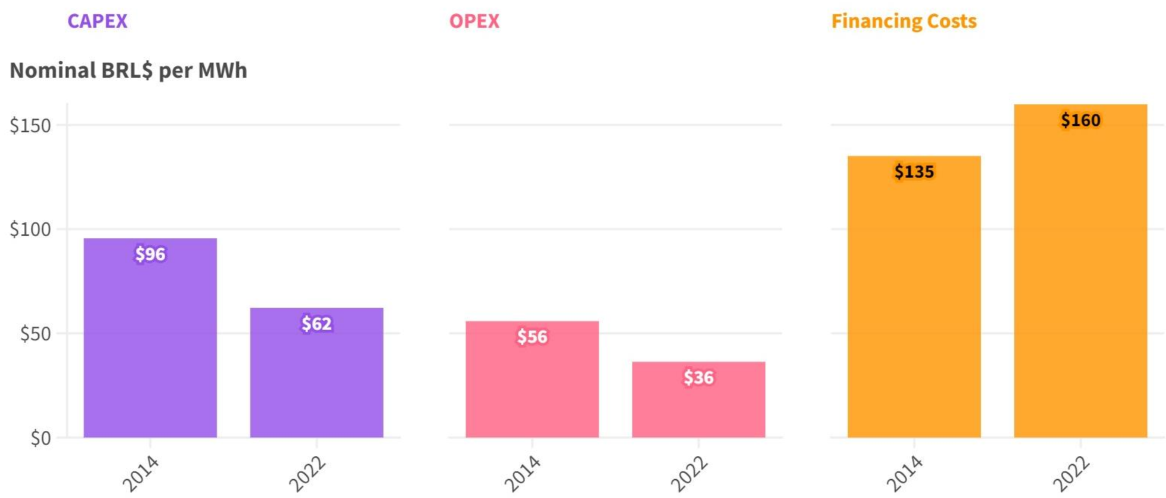

Figure 8. Changes in Financing Costs from 2014 to 2022.

The findings align with broader literature on renewable energy finance in emerging markets. Egli et al. (2018) noted that financing costs can offset technological gains in certain market conditions. This underscores the importance for investors of sophisticated financial structuring and risk management strategies. Access to low-cost capital and effective hedging against macroeconomic risks may become crucial for maintaining project competitiveness.

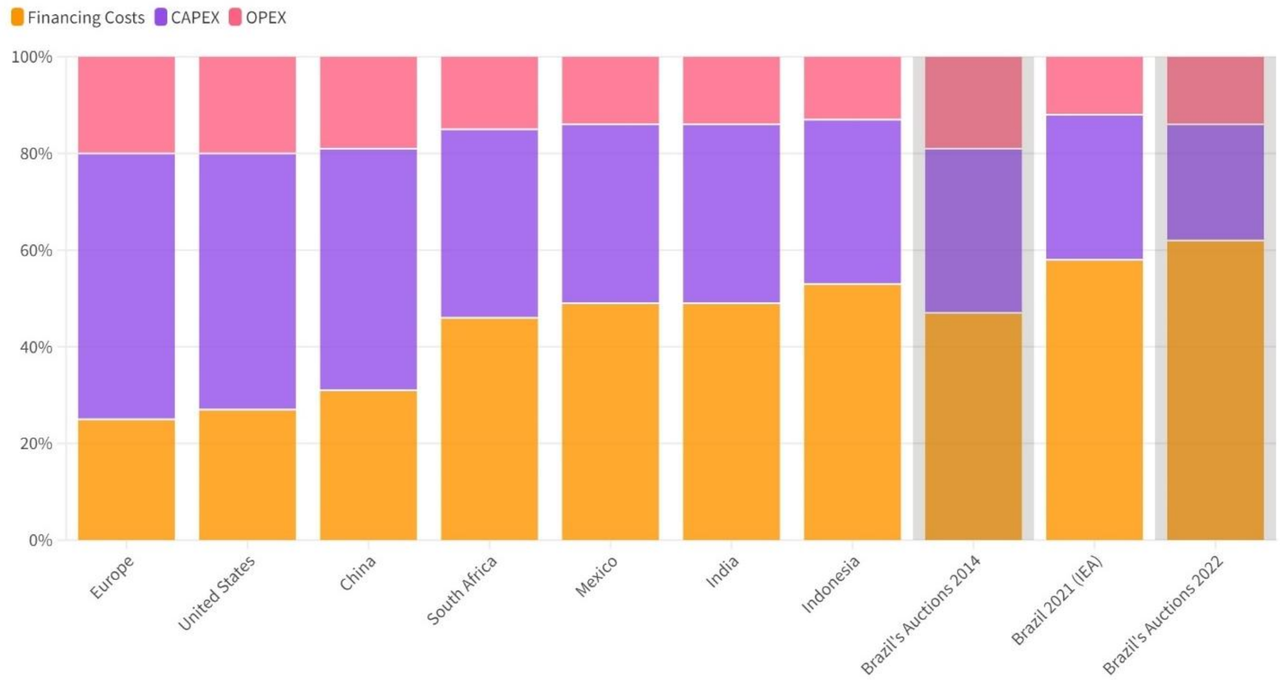

Figure 9. Financing Costs Estimated by IEA with 2021 assumptions v. own estimations of Brazil's Auctions in 2014 and 2022. Grey-shaded areas are estimations done in this paper, the rest were done by the IEA. Data source: IEA (2023).

The comparison of solar PV financing costs across regions reveals significant disparities, with Brazil's case highlighting unique challenges in emerging markets (IEA, 2024b). The increase in Brazil's financing costs from 47% in 2014 to 62% in 2022, despite global trends of decreasing technology costs, underscores the complex interplay between macroeconomic factors and renewable energy economics discussed in the Brazilian context section. The higher financing costs in Brazil compared to Mexico and India, estimated by the IEA (2024b), suggest country-specific factors at play, potentially including the currency depreciation and inflation risks noted previously.

These results add nuance to the understanding of solar PV economics in Brazil, demonstrating that technological improvements alone may not guarantee cost reductions. The cancellation of several projects due to currency depreciation, further emphasises the critical impact of macroeconomic volatility on project viability. This reinforces the need for policies that can mitigate currency risks and improve the overall investment climate for renewable energy in Brazil (IEA, 2024b).

The fact that Brazil's financing costs are higher than those of comparable developing countries like Mexico and India highlights the need for targeted policy interventions to reduce capital costs, which could include measures to enhance policy stability, improve macroeconomic conditions, or develop innovative financing mechanisms tailored to the Brazilian context. Addressing these high financing costs should be a priority for policymakers aiming to accelerate solar PV deployment in Brazil and similar emerging markets.

The scenario analysis for Brazil's bond yields and inflation rates from 2024 to 2029 in Level 3 provides crucial insights into the potential trajectories of solar PV financing costs. This approach, incorporating Flat, Upward, and Downward scenarios, addresses the significant uncertainty in Brazil's economic outlook highlighted in the macroeconomic landscape analysis.

The historical data in Figure 10 illustrates Brazil's economic volatility over the past decade. The peak bond yield of 16.5% in 2015-2016 coincides with Brazil's deepest recession in recent history, as described in the macroeconomic landscape analysis. This period was marked by severe political instability, including the impeachment of President Dilma Rousseff, and widespread corruption investigations that disrupted major economic sectors. The subsequent decline in bond yields and inflation rates from 2016 to 2020 reflects the gradual economic recovery and the implementation of more orthodox economic policies under the Temer and early Bolsonaro administrations.

The sharp rise in both bond yields and inflation in 2021-2022 aligns with the global inflationary pressures and supply chain disruptions following the COVID-19 pandemic, compounded by domestic factors such as severe drought affecting hydroelectric power generation and increasing political uncertainty leading up to the 2022 elections. This recent volatility underscores the challenges in predicting Brazil's macroeconomic trajectory, justifying the multi-scenario approach.

The Flat Scenario, maintaining the average yield of 11.4% from January to June 2024, represents a cautious middle ground. It assumes that Brazil's central bank will successfully navigate the current inflationary pressures without significant economic disruption. The Upward scenario, projecting yields to return to the historical peak of 16.49%, reflects the potential for continued economic challenges and policy uncertainties. It also accounts for the potential fiscal pressures that could arise from expansionary policies under the new Lula administration.

Conversely, the Downward scenario, with yields decreasing to the historical low of 6.3%, represents an optimistic outlook. This scenario assumes successful implementation of fiscal reforms, inflation control, and a stable political environment conducive to investment. Such conditions could potentially lead to a ‘financing experience effect’ as described by Egli et al. (2018), where improved macroeconomic conditions and policy stability contribute to lower financing costs for renewable energy projects over time.

This approach allows for quantification of the potential impacts of Brazil's macroeconomic volatility on solar PV financing, addressing a key gap identified by Steffen (2020) in the literature on renewable energy financing in emerging markets.

The impact of these scenarios on financing costs is striking. In the Flat scenario (Figure 11), financing costs remain relatively stable, decreasing slightly from 48% to 46% of total project costs. This scenario aligns with the cautious optimism expressed by some analysts regarding Brazil's economic stability post-2023. As noted in the macroeconomic landscape analysis, the return of Luiz Inácio Lula da Silva to the presidency in 2023 signalled potential shifts in economic policy, with a greater emphasis on social spending and public investment. This flat scenario could represent a delicate balance achieved between expansionary policies and fiscal discipline.

The Upward scenario paints a more challenging picture, with financing costs rising from 48% to 55% of total project costs. This scenario reflects the potential risks highlighted in the macroeconomic analysis, including the possibility of rising public debt (projected by the IMF to potentially reach 95% of GDP by 2029) and the challenges of maintaining investor confidence while implementing new social and economic policies. This scenario aligns with the concerns raised by Schmidt et al. (2019) regarding the vulnerability of renewable energy investments to macroeconomic instability in emerging markets.

Conversely, the Downward scenario shows financing costs decreasing from 48% to 38%, representing a significant improvement in investment conditions. This optimistic outlook could be realised if Brazil successfully implements fiscal reforms, controls inflation, and creates a stable political environment conducive to investment and the ‘financing experience effect’.

All scenarios include a learning rate for both CAPEX and OPEX, reflecting global trends in solar PV technology. However, the divergence in financing costs across scenarios underscores the crucial role of country-specific economic factors in determining overall project viability. These projections also highlight the potential limitations of relying solely on technology cost reductions to drive solar PV deployment in emerging markets. As demonstrated in the Level 2 analysis, despite significant reductions in CAPEX and OPEX from 2014 to 2022, the overall LCOE for solar PV projects in Brazil increased due to rising financing costs.

This scenario analysis reveals a critical tension in Brazil's renewable energy future. While global trends continue to drive down technology costs, the country's macroeconomic management emerges as the pivotal factor in determining the viability of solar PV projects. This suggests that the most effective policy interventions for accelerating solar deployment in Brazil may lie more in the realm of macroeconomic policy and financial market development than in renewable energy-specific incentives. The analysis underscores the need for a holistic approach to renewable energy policy in emerging markets, one that considers the broader economic context alongside sector-specific measures.

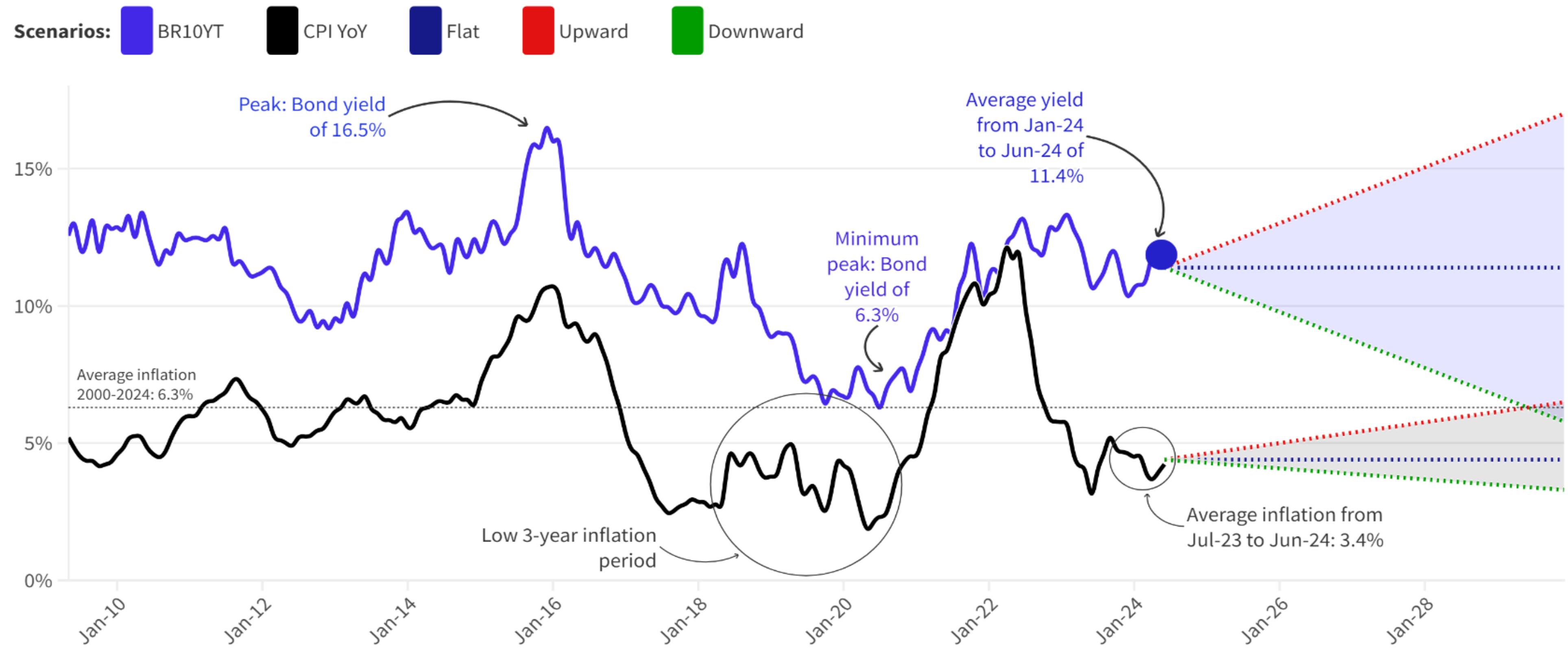

Figure 10. Three Scenarios for Bond Yields and Inflation: Flat, Upward and Downward

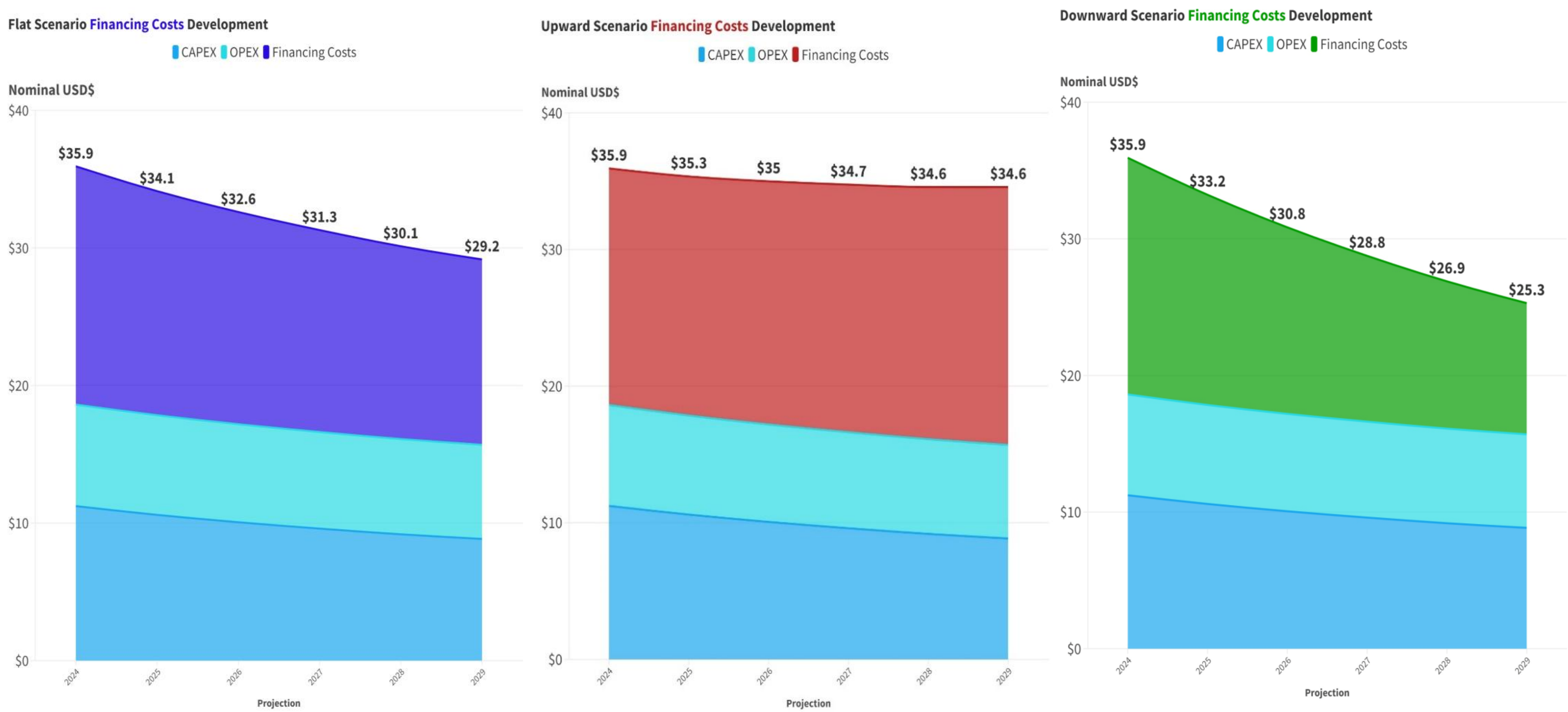

Figure 11. Development of Financing Costs per Scenario

Conclusion

Solar PV is expanding rapidly, with global manufacturing capacity set to exceed 1 TW/a by the end of 2024, all while costs keep decreasing. According to the IEA, solar PV is expected to satisfy nearly half of the growth in global electricity demand over 2024 and 2025. Investment patterns reflect this, with twice the amount of money spend on clean energy than on fossil fuels (IEA, 2024b). Despite these positive trends, the financial structure of renewable energy substantial requires upfront investment, making them susceptible to macroeconomic shocks and country-specific risks.

This study examines the complex interactions between financing conditions and the LCOE for solar PV projects in Brazil, from 2014 to 2024, using a multi-tiered approach (see Methodology): (1) Calculating a monthly WACC, (2) estimating the LCOE for projects awarded through auctions, and (3) projecting financing scenarios from 2024 to 2029. Our results show that CAPEX and OPEX decrease over time, but these cost reductions were counteracted by rising financing costs, especially during periods of macroeconomic instability.

As a result, the volatility in financing conditions has prevented a smooth decline in LCOE, despite consistently falling technology costs. Financing costs – which now account for a significant portion of total project costs – have remained elevated owed to inflation, high interest rates, and country risk premiums. This research thus emphasises the impact of finance in Brazil and other emerging markets, where financing costs will determine the pace of renewable energy adoption. Macroeconomic conditions can significantly alter the cost structure of projects (IEA, 2021), highlighting the need for financial risk mitigation strategies that go beyond technology cost reductions (Aguila & Wullweber, 2024). While technological advancements are imperative, a stable financial environment is equally critical for unlocking the full potential of renewable energy in emerging markets, such as Brazil.

Future research could incorporate project-level finance data, particularly from private investors and outside of auctions. It should also study the impact on the WACC by newly implemented import tariffs on solar PV panels. Furthermore, Brazil's free market environment (ACL) deserves attention, which is likely more competitive than the auction markets. Of further interest would be the overall project profitability, not just cost. A broader, comparative understanding in the context of other emerging markets would help piecing together an understanding of macroeconomic environments affect renewable energy financing globally.

The findings of this study reinforce the critical role of financial stability in complementing technological advancements to drive renewable energy adoption in emerging markets.

Bridging the gap between investment needs and financial risks in emerging markets allows solar PV’s contribution to a resilient and sustainable energy future globally. This will become even more relevant as solar PV becomes central to satisfying global energy demand, thus creating stable financing frameworks in emerging markets, like Brazil, will be key to meeting climate and energy goals.

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Credit Statement

Santiago Monroy Gomez: Conceptualisation, Methodology, Software, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Visualisation **Malte Jansen:** Conceptualisation, Writing - Review & Editing, Supervision

Data and code availability

The datasets and code produced in this study are available in the ZENODO repository, DOI: https://doi.org/10.5281/zenodo.14529054. The code is organised in Jupyter notebooks for Python. See ReadMe file in the Zenodo repository for instructions.

Acknowledgements

The authors would like to thank members of the IEA TCP Wind Task 53, in particular Philipp Beiter, for their fruitful discussion.

Annex 1: Additional Figures

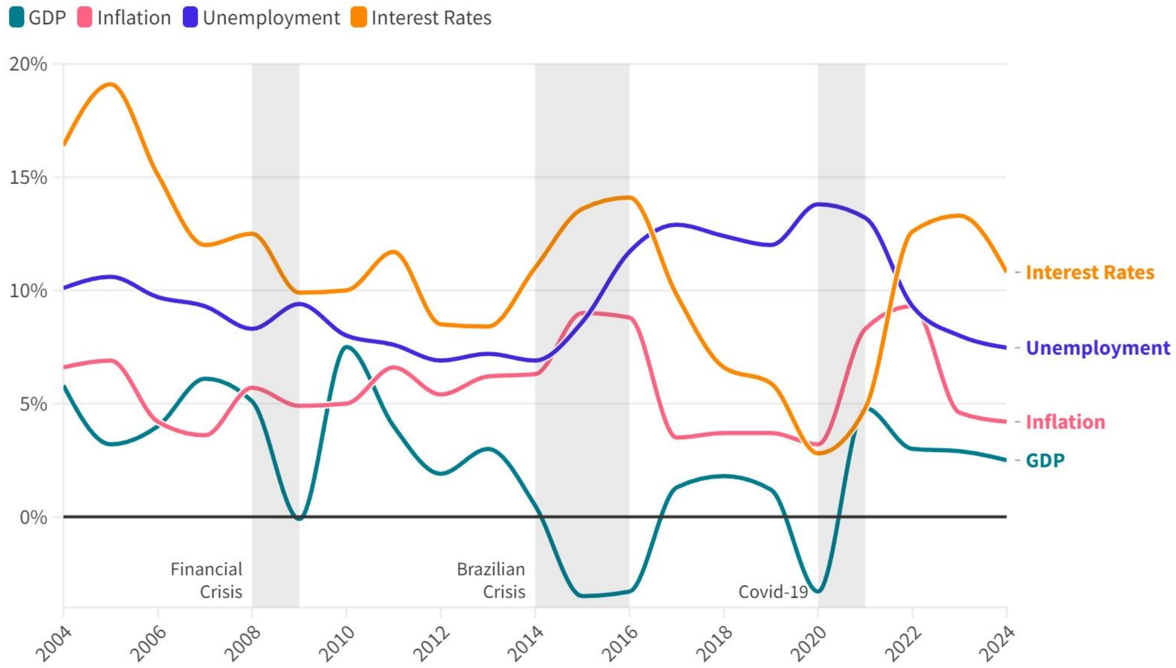

Figure A12. Brazil's GDP, Inflation, Unemployment, and Interests Rates. Brazil has experienced a lot of volatility in the past two decades with volatility in all macroeconomic indicators. Data source: IMF (2024); IBGE (2024); Refinitiv (2024). GDP value for 2024 makes reference to IQ 2024; the rest are averages from Jan-24 to Jun-24.

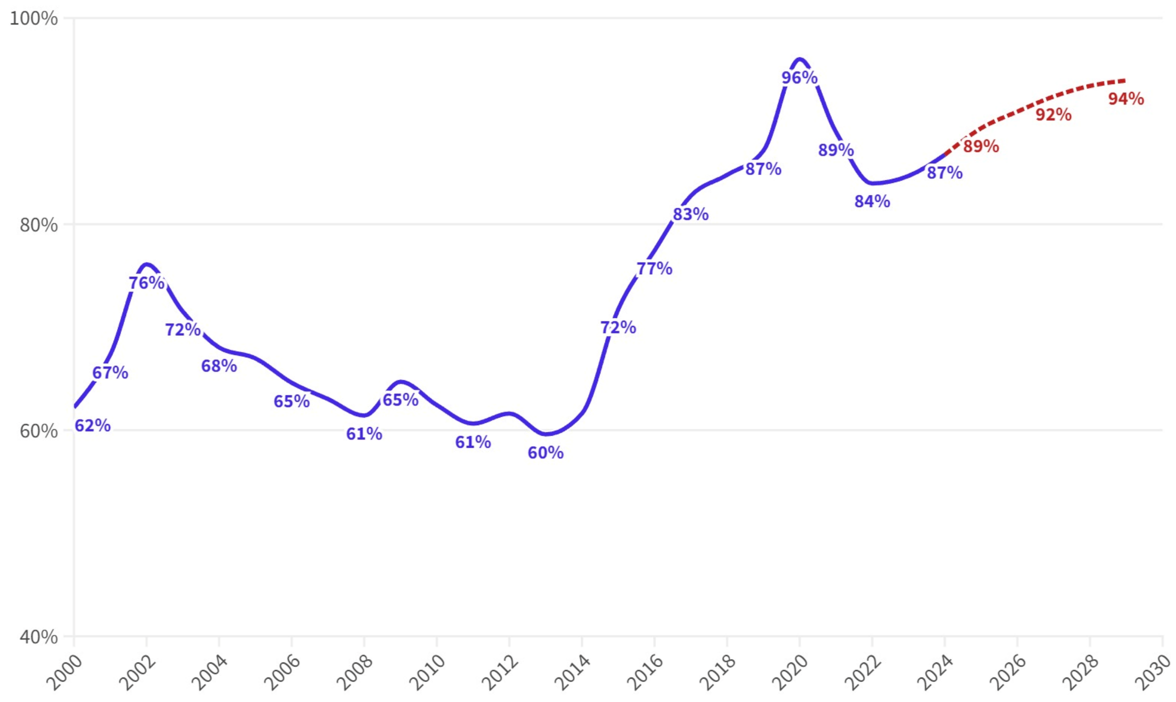

Figure A13. Rising Tide: Brazil's Debt/GDP Ratio Past Peaks and Future Projections. Although Brazil was slowly decreasing its debt as a percentage of its GDP, after the 2016 crisis, the debt-GPD ratio grew dramatically. The IMF projects Brazil's GDP to reach 94% in 2029. Data source: IMF (2024)

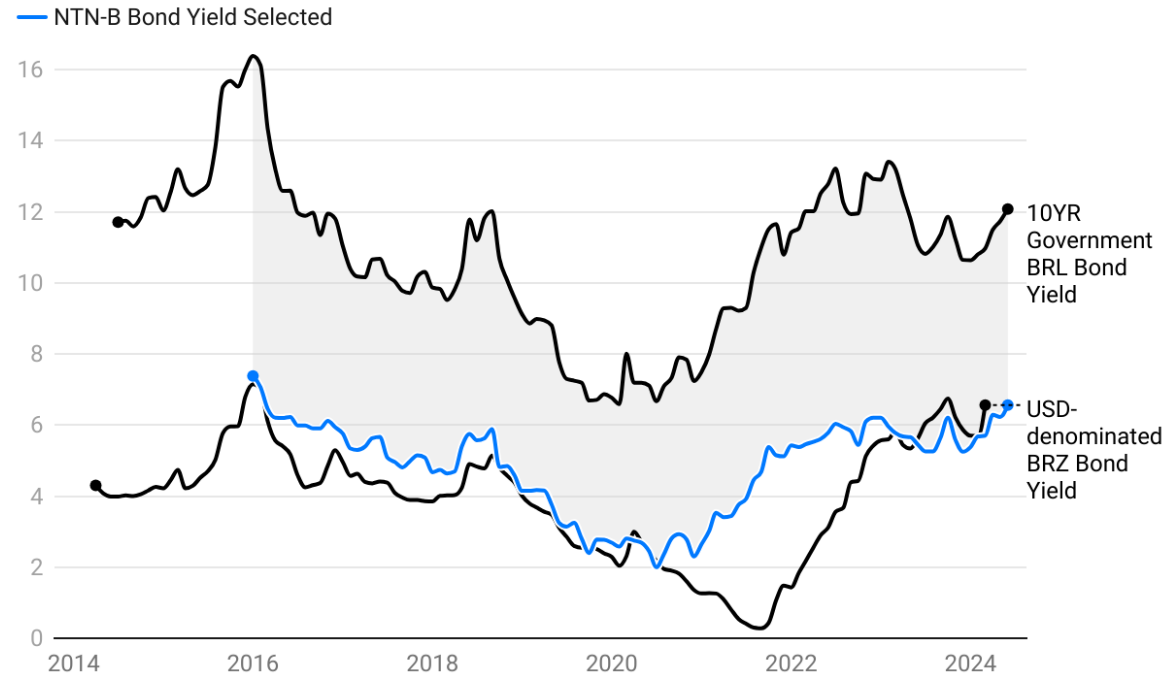

Figure A14. Bond yields of three different instruments considered for the WACC methodology. The US$-denominated bond yield was not incorporated in the final estimate, as it is considered that US$-denominated bond yields for country-specific estimations were used by IRENA to exclude currency risks and make comparison between countries straightforward. Furthermore, the yield on the bond has unrealistically low periods, even having a negative spread during some months when compared to the 10 YR US Treasury bond yield Moreover, the 10 YR Government BRL Bond Yield has incredibly high yields, which if considered for both cost of debt and cost of equity would've resulted in unrealistic cost of equities. So, a nuanced approach was selected: NTN-B bond yield. Data sources: Bloomberg, LSEG, Brazil's Central Bank.

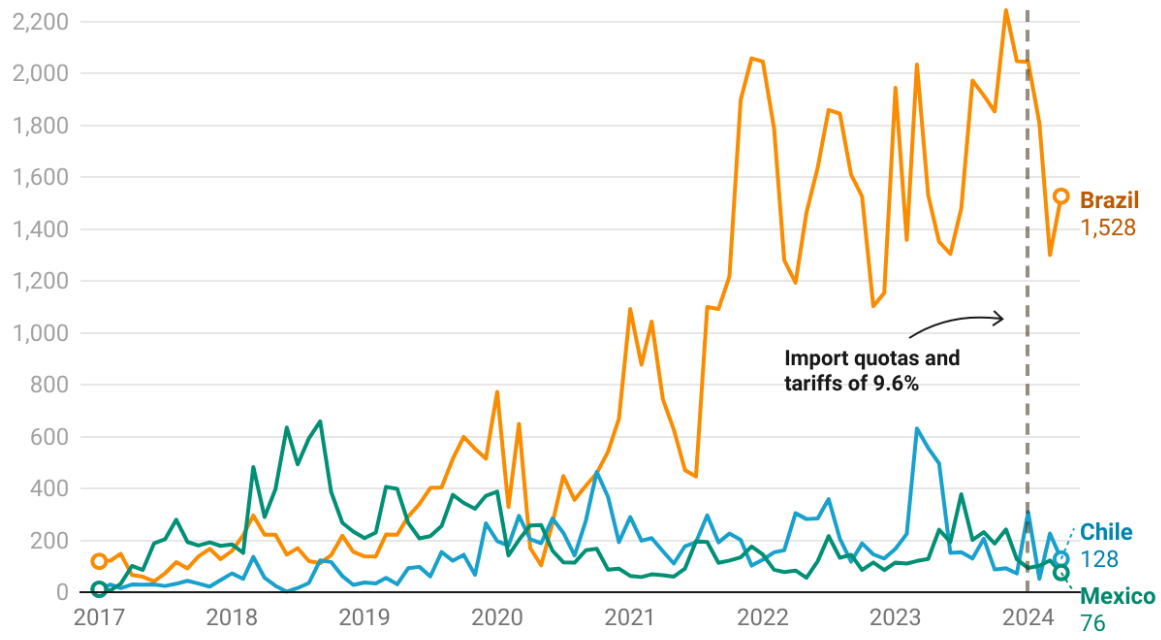

Figure A15. Solar Panel Imports from China in MW. Brazil imports around 99% of its solar panels from China. The rest is locally produced, with an average cost of +50% compared with Chinese solar panels. Data source: EMBER (2024b)

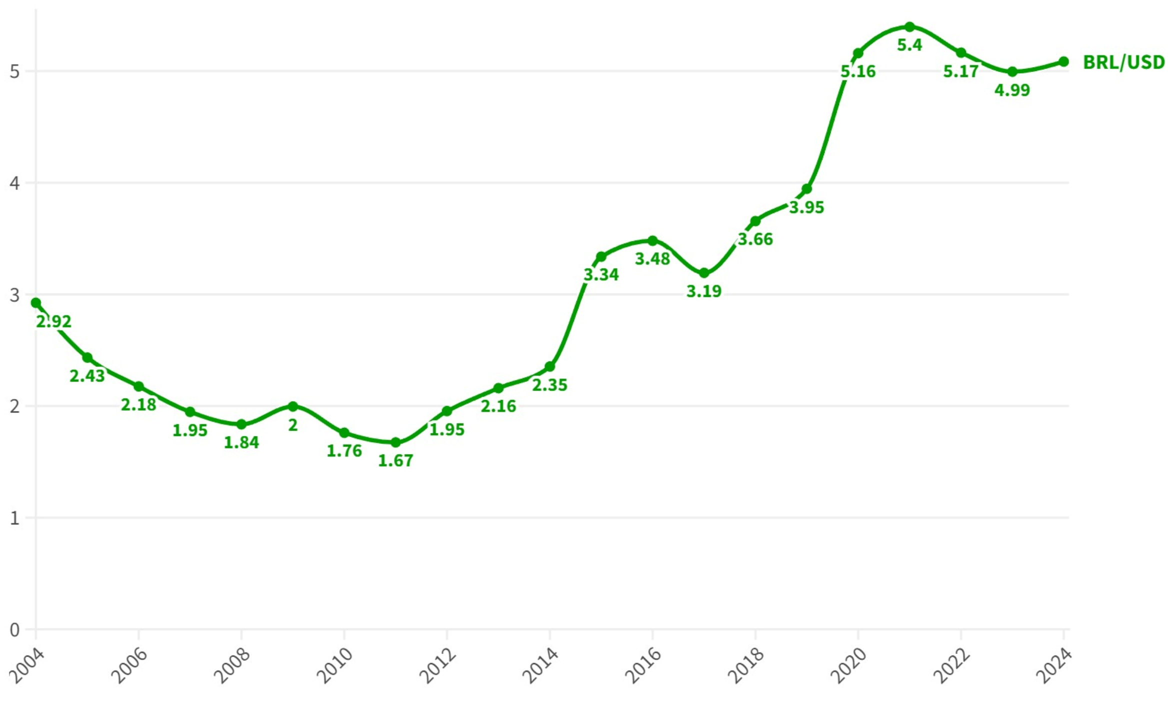

Figure A16. BRL/US$ exchange rate 2004-2024. The Brazilian real weakened against the dollar in the past two decades. It is one of the most depreciated currencies. Data source: Bloomberg (2024)

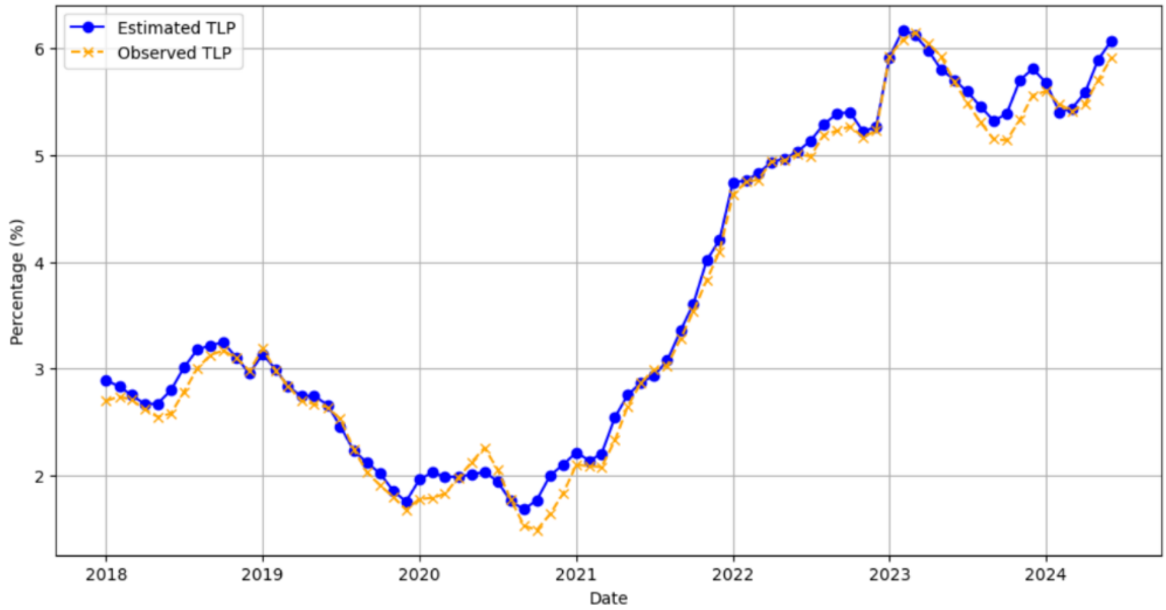

Figure A17. Estimated Long-term Rate (TLP) v. Observed TLP given rate (without inflation) 2018 – 2024. Data source: Refinitiv Workspace (2024) (now owned by LSEG).

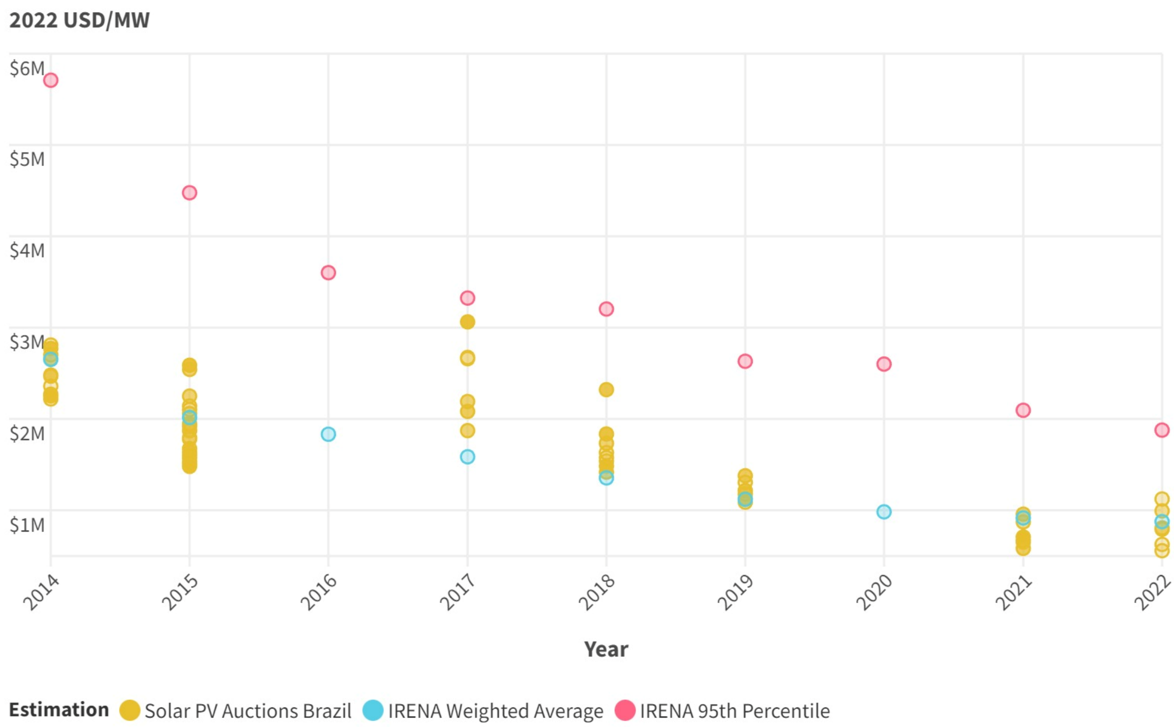

Figure A18. Capital Expenditures of Solar PV Auctions Brazil v. IRENA. The CAPEX estimated for the projects on our dataset are in line with the IRENA's global weighted average estimation. Data sources: CCEE (2024); IRENA (2023)

Figure A19. Capacity Factors from Solar PV projects in Brazil. Data sources: CCEE (2024); IRENA (2023)

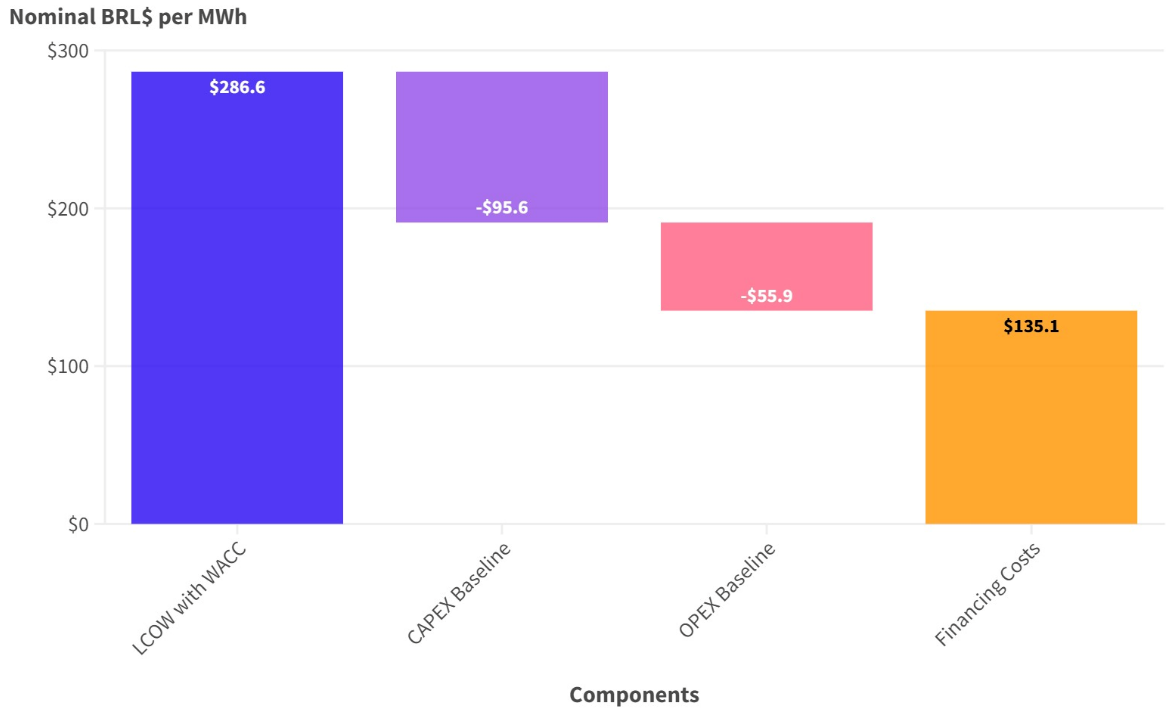

Figure A20. Financing Costs (Baseline LCOE needs to be subtracted from the LCOE with WACC)

Annex 2: Description of source and datasets used for the methodology

Refinitiv Workspace Data

Refinitiv Workspace was used to source monthly values for several key financial indicators:

- US government bond yields
- US$-denominated Brazilian Government bond yield
- 10-year BR10YT Government bond yield
- 5-year NTN-B bond yield
- IPCA (CPI) Year-over-Year

These data were crucial for calculating the cost of debt and assessing macroeconomic conditions in Brazil. The use of monthly values allowed for a detailed analysis of trends and fluctuations over time.

Bloomberg Terminal

- Exchange rate BRL/US$

BNDES (Brazilian Development Bank) Rates:

Data on BNDES rates were sourced directly from the official BNDES website. Two types of rates were collected:

a) Subsidized rate (TJLP - Taxa de Juros de Longo Prazo):

- Updated quarterly
- Determined by the National Monetary Council (Conselho Monetário Nacional - CMN)
- Historical data available from its inception

b) Unsubsidized rate (TLP - Taxa de Longo Prazo):

- Updated monthly
- Data available from its creation in January 2018

These rates are essential for understanding the financing conditions for infrastructure projects, including solar PV, in Brazil.

Energy Auction Dataset

This comprehensive dataset contains information on winning projects from energy auctions in Brazil since 2004. Key characteristics include:

- 48 variables for each project
- 2,139 total winning projects across all energy sources
- 195 solar PV projects
- Publicly available
- Updated monthly with inflation adjustments

For this study, nominal values were used to analyse macroeconomic and financing conditions at the time of each auction.

Annex 3: Additional Tables

Table A1: Energy Auction Dataset Variables

Variable	Description
ID	Unique identifier for each project
Year of auction	Year the auction took place
Type of auction	Classification of the auction type
Auction	Specific auction identifier
Auction denomination	Full name or description of the auction
Notice number	Official notice number for the auction
Seller name	Name of the company or entity selling the energy
CNPJ	Brazilian company registration number
Product	Type of energy product being sold
CEG	Generation unit code
Power plant name	Name of the power plant
Status	Current status of the project
State	Brazilian state where the project is located

Variable	Description
Source	Energy source (e.g., solar, wind, hydro)
River/fuel	Specific river for hydro or fuel type for thermal
Subdivisions	Any relevant subdivisions of the project
Investment at Auction Date (Million Reais)	Initial investment amount
Updated Investment (Million Reais)	Investment amount adjusted for inflation
Capacity (MW)	Installed capacity of the project
Physical guarantee (MW average)	Assured energy production
Energy Negotiated for Year A-A+3 (MW average)	Energy contracted for specific years
Energy Negotiated for Remaining Years (MW average)	Energy contracted for years beyond A+3
Total energy contracted (MWh)	Total amount of energy sold in the auction
Sale Price or ICB on Auction Date (R$/MWh)	Initial sale price
Price Unit	Unit of measurement for the price
Financial Amount Negotiated per Contract (R$)	Total financial value of the contract
Updated Sale Price (R$/MWh)	Sale price adjusted for inflation

Variable	Description
Updated Financial Amount Negotiated	Financial value adjusted for inflation
Fixed Revenue per Contract for Years A-A+1 (R$/year)	Guaranteed revenue for initial years
Fixed Revenue per Contract for Remaining Years (R$/year)	Guaranteed revenue for later years
Supply Start Date	Date when energy supply is set to begin
Supply End Date	Date when energy supply contract ends
IPCA on auction date	Inflation index at the time of the auction
IPCA June/2024	Inflation index used for updates

Annex 3: Additional Article methodology

Three Jupyter Notebooks:

/ Dissertation / Dissertation Notebooks /

- Name
- cost-of-capital.ipynb
- lcoe.ipynb
- scenario-projection.ipynb

CSV Files used throughout the Notebooks:

/ Dissertation / DIssertation CSV Files /

- Name
- bndes_wacc_calculations.csv
- bndes-rates.csv
- currency-brl-usd.csv
- erp-mature-market-sp500.csv
- lcoe_solar_analysis.csv
- projected_ntnb_yields.csv
- scenarios_solar.csv
- scenarios-solar.csv
- selic-and-bond-yields.csv
- solar-auctions.csv
- solar-installed-capacity.csv
- us-cpi.csv
- us-treasury-yield.csv
- yield-correlation.csv

First Jupyter Notebook on Cost of Capital: Calculating the BNDES rate.

```
[3]: bndes['date'] = pd.to_datetime(bndes['date'], format='%b-%y')
```

```
[4]: alpha_factors = {
    2018: 0.57,
    2019: 0.66,
    2020: 0.74,
    2021: 0.83,
    2022: 0.91,
    2023: 1.00,
    2024: 1.00
}
```

```
[5]: bndes['alpha'] = bndes['date'].dt.year.map(alpha_factors)
```

```
[6]: bndes['ntnb_5yr_yield_ma'] = bndes['ntnb_5yr_yield'].rolling(window=3).mean().shift(1)
```

```
[7]: bndes['est_bndes_tlp'] = bndes['alpha'] * bndes['ntnb_5yr_yield_ma']
```

```
[9]: bndes['obs_tlp_ipca'] = bndes['cpi_ipca'].shift(1) + bndes['obs_bndes_tlp']
```

```
[10]: bndes['bndes_rate'] = bndes['bndes_tjlp'].combine_first(bndes['obs_tlp_ipca'])
```

Calculating the Global risk-free rate, country default spread and technology premium:

```
[17]: bndes['cds_brazil'] = bndes['bndes_rate'] - bndes['us_treasury_yield']
```

```
[18]: bndes[['date', 'bndes_rate', 'us_treasury_yield', 'cds_brazil']].tail()
```

[18]:

	date	bndes_rate	us_treasury_yield	cds_brazil
121	2024-02-01	9.99	4.250	5.740
122	2024-03-01	9.91	4.200	5.710
123	2024-04-01	9.41	4.680	4.730
124	2024-05-01	9.39	4.499	4.891
125	2024-06-01	9.84	4.396	5.444

Adding the technology premium based on solar installed capacity

[23]:
```
def calculate_technology_premium(solar_capacity_ratio):
    #For new markets a linear interpolation between 3.25% and 3% for 0% to <5% capacity
    if solar_capacity_ratio < 5:
        return 3.25 - (0.25 * (solar_capacity_ratio / 5))
    #For intermediate markets a linear interpolation between 3% and 1.7% for 5% to <10% capacity
    elif 5 <= solar_capacity_ratio < 10:
        return 3.0 - (1.3 * ((solar_capacity_ratio - 5) / 5))
    #For mature markets of 10% and above a fixed premium is assigned
    else:
        return 1.5
```

[24]:
```
bndes['technology_premium'] = bndes['solar_capacity_ratio'].apply(calculate_technology_premium)
```

Applying the tax shield:

[28]:
```
corporate_tax_rate = 0.34
bndes['cost_of_debt'] = bndes['pre_tax_cost_of_debt'] * (1 - corporate_tax_rate)
```

Calculating cost of equity:

[34]:
```
bndes['cost_of_equity'] = (
    bndes['us_treasury_yield'] +
    bndes['cds_brazil'] +
    bndes['erp_sp500'] +
    bndes['technology_premium']
)
```

Debt share and WACC:

Debt share as per IRENA criteria (based on cumulative installed capacity)

[37]:
```
def assign_debt_share(solar_capacity_ratio):
    #Mature market
    if solar_capacity_ratio >= 10:
        return 0.80
    #Intermediate market
    elif 5 <= solar_capacity_ratio < 10:
        return 0.70
    #New market
    else:
        return 0.60
```

[38]:
```
bndes['debt_share'] = bndes['solar_capacity_ratio'].apply(assign_debt_share)
```

Calculating cost of capital (WACC)

[39]:
```
bndes['cost_of_capital'] = (
    bndes['cost_of_debt'] * bndes['debt_share'] +
    bndes['cost_of_equity'] * (1 - bndes['debt_share'])
)
```

Second Jupyter Notebook on LCOE:

Dataset:

```
[4]: lcoe_solar.head()
```

[4]:

	date	name_auction	seller_name	power_plant_name	capex	nominal_capacity_mw	physical_guarantee_mwave	energy_contracted	sale_price_auction	fir
0	31/10/2014	06ºLER	RIO ENERGY EOL IV	SOLAR CAETITÉ 3	140007000	29.97	6.6	1157112.0	207.52	
1	31/10/2014	06ºLER	RIO ENERGY EOL IV	SOLAR CAETITÉ 2	140007000	29.97	6.6	1157112.0	207.52	
2	31/10/2014	06ºLER	RIO ENERGY EOL IV	SOLAR CAETITÉ 1	140007000	29.97	6.6	1157112.0	207.52	
3	31/10/2014	06ºLER	DRACENAS	DRACENA 4	128320000	30.00	5.9	1034388.0	217.75	
4	31/10/2014	06ºLER	DRACENAS	DRACENA 1	128320000	30.00	5.9	1034388.0	217.75	

LCOE Baseline for each project:

```
[16]: lcoe_solar['lcoe_baseline'] = lcoe_solar['capex_baseline'] + lcoe_solar['opex_baseline']
      lcoe_solar[['power_plant_name', 'capex_baseline', 'opex_baseline', 'lcoe_baseline']].head()
```

[16]:

	power_plant_name	capex_baseline	opex_baseline	lcoe_baseline
0	SOLAR CAETITÉ 3	96.863844	56.58174	153.445584
1	SOLAR CAETITÉ 2	96.863844	56.58174	153.445584
2	SOLAR CAETITÉ 1	96.863844	56.58174	153.445584
3	DRACENA 4	99.311199	58.01133	157.322529
4	DRACENA 1	99.311199	58.01133	157.322529

Cost of capital for each project:

[22]:

	power_plant_name	date	cost_of_capital
0	SOLAR CAETITÉ 3	2014-10-31	8.738336
1	SOLAR CAETITÉ 2	2014-10-31	8.738336
2	SOLAR CAETITÉ 1	2014-10-31	8.738336
3	DRACENA 4	2014-10-31	8.738336
4	DRACENA 1	2014-10-31	8.738336

LCOE with WACC for each project:

[30]:

	power_plant_name	capex_wacc	opex_wacc	lcoe_wacc
0	SOLAR CAETITÉ 3	241.326448	48.983134	290.309582
1	SOLAR CAETITÉ 2	241.326448	48.983134	290.309582
2	SOLAR CAETITÉ 1	241.326448	48.983134	290.309582
3	DRACENA 4	247.423785	50.220738	297.644524
4	DRACENA 1	247.423785	50.220738	297.644524

Financing Costs:

[32]:
```
lcoe_wacc_2022 = lcoe_solar[lcoe_solar['year'] == 2022]['lcoe_wacc'].mean()
lcoe_baseline_2022 = lcoe_solar[lcoe_solar['year'] == 2022]['lcoe_baseline'].mean()
delta_2022 = lcoe_wacc_2022 - lcoe_baseline_2022
print(delta_2022)
```

```
159.84377858181443
```

[33]:
```
delta_i = delta_2022 - delta_2014
```

[34]:
```
print(f"Change in financing costs from 2014 to 2022: {delta_i.round(2)} BRL/MWh.")
```

```
Change in financing costs from 2014 to 2022: 24.74 BRL/MWh.
```

Third Jupyter Notebook on Future Financing Costs:

Correlation and regression:

[4]:
```
correlation_matrix = df.corr()
correlation_matrix
```

[4]:

	ntnb_5yr_yield	cpi_ipca	yr10_gov_bond_yield
ntnb_5yr_yield	1.000000	0.354614	0.962594
cpi_ipca	0.354614	1.000000	0.490069
yr10_gov_bond_yield	0.962594	0.490069	1.000000

[13]:
```
X_diff = sm.add_constant(df_diff['diff_yr10_gov_bond_yield'])
model_diff = sm.OLS(df_diff['diff_ntnb_5yr_yield'], X_diff).fit()
```

[14]:
```
residuals_diff = model_diff.resid
```

```
[17]: model_diff_summary = model_diff.summary()
      adf_diff_results, model_diff_summary
```

```
[17]: ({'diff_ntnb_5yr_yield': 3.2469943886149468e-12,
        'diff_yr10_gov_bond_yield': 4.5221297702752256e-10},
       <class 'statsmodels.iolib.summary.Summary'>
       """
                                   OLS Regression Results
       ==============================================================================
       Dep. Variable:     diff_ntnb_5yr_yield   R-squared:                       0.614
       Model:                             OLS   Adj. R-squared:                  0.609
       Method:                  Least Squares   F-statistic:                     124.1
       Date:                 Sat, 07 Sep 2024   Prob (F-statistic):           8.47e-18
       Time:                         21:18:32   Log-Likelihood:                 15.086
       No. Observations:                   80   AIC:                            -26.17
       Df Residuals:                       78   BIC:                            -21.41
       Df Model:                            1
       Covariance Type:            nonrobust
       ============================================================================================
                                      coef    std err          t      P>|t|      [0.025      0.975]
       --------------------------------------------------------------------------------------------
       const                        0.0067      0.023      0.295      0.768      -0.039       0.052
       diff_yr10_gov_bond_yield     0.4292      0.039     11.142      0.000       0.353       0.506
       ==============================================================================
       Omnibus:                        0.750   Durbin-Watson:                   2.281
       Prob(Omnibus):                  0.687   Jarque-Bera (JB):                0.360
       Skew:                           0.141   Prob(JB):                        0.835
       Kurtosis:                       3.167   Cond. No.                         1.70
       ==============================================================================

       Notes:
       [1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
       """)
```

Definition of scenarios for 2029:

```
[26]: avg_yield_inflation_2029 = projected_yields[projected_yields['Date'].dt.year == 2029].mean()
      print(avg_yield_inflation_2029)
```

```
Date                    2029-06-16 12:00:00
Flat_10YR_Yield                        11.4
Upward_10YR_Yield                 16.532417
Downward_10YR_Yield                  6.2575
Flat_Inflation                          4.4
Upward_Inflation                   6.315833
Downward_Inflation                 3.391667
dtype: object
```

WACC Evolution under scenario assumptions:

[44]:

Year	WACC_Flat	WACC_Upward	WACC_Downward
2024	9.497786	9.497786	9.497786
2025	9.497787	10.064794	9.066732
2026	9.497787	10.660108	8.601831
2027	9.497787	11.255423	8.136930
2028	9.497787	11.850738	7.672029
2029	9.497787	12.446053	7.207129

Learning Rates Assumptions:

[45]:
```
capex_2022 = 167735285.6  # in nominal BRL for 2022
opex_2022 = 2430484.3  #EPE report 1.45%
capex_learning_rate = 0.15
opex_learning_rate = 0.05
inflation_rate = 0.04  # 4% annual inflation
nominal_power = 40  # Average MW for 2022
capacity_factor = 0.313447745 #Average 2022
lifetime = 25  # Project lifetime in years
hours_per_year = 8760  # Total hours in a year
```

[46]:
```
# Capacity totals for each year starting from 2023
capacity_total = {
    2023: 1628,
    2024: 2167,
    2025: 2781,
    2026: 3469,
    2027: 4241,
    2028: 5117,
    2029: 6000
}
```

LCOE Baseline and Scenarios:

[65]:

Year	LCOE_Baseline	LCOE_WACC_Flat	LCOE_WACC_Upward	LCOE_WACC_Downward
2024	94.661103	182.740612	182.740612	182.740612
2025	90.729005	173.569656	179.728889	168.957855
2026	87.409649	165.860944	177.932398	156.843084
2027	84.520325	159.177377	176.708222	146.234089
2028	81.925455	153.197274	175.799433	136.742334
2029	79.801921	148.320031	175.774645	128.628774

Financing Costs evolution:

[66]:

Year	Financing_Cost_Flat	Financing_Cost_Upward	Financing_Cost_Downward
2024	88.079509	88.079509	88.079509
2025	82.840651	88.999883	78.228850
2026	78.451295	90.522749	69.433435
2027	74.657051	92.187897	61.713764
2028	71.271819	93.873978	54.816879
2029	68.518109	95.972724	48.826853