

Regulatory Cost of Capital of the Brazilian Electricity Distribution Companies: A Proposed Modeling by Time Series

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Abstract

Objective: The aim of this paper was to propose the use of time series models to forecast long series components of the regulatory WACC of the Brazilian electricity distributors, instead of the mean or median used by ANEEL.

Method: To calculate the regulatory WACC components in the first five CRTPs and the proposed WACC, we used the same database employed by ANEEL, available on its website. ARMA and AR models were used to estimate the long series components USTB, S&P500, EMBI+, and CPI, find the proposed WACC, and subsequently compare it with the ANEEL WACC in the first five CRTPs.

Results: The estimates from time series models were different from those calculated by ANEEL for the components in the first five CRTPs. Thus, the regulatory WACC was reduced in some CRTPs and increased in others. On average, the values obtained in this study are lower than those of ANEEL, but the differences are very small. The components estimated by time series models, as well as the WACC, oscillated more along the five CRTPs compared to those of ANEEL.

Contributions: This paper's contribution was broadening the discussion on the methods of supporting the investment decisions of regulated companies. We consider the models proposed more appropriate because the series of the regulatory WACC components may be non-stationary and have an autocorrelation structure. In that case, their means or medians would not be appropriate estimates of future values.

Keywords: Cost of Capital. Regulatory WACC. Time Series Models.

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Introduction

The investment decision-making process in companies essentially involves evaluating their risk and return conditions. The selection of investments that offer the best risk-return relationship and the choice of resources to finance them are fundamental factors for companies' value because they determine the cost of capital. These decisions are particularly relevant in strategic sectors for countries' development, such as the electric sector. In emerging economies, in particular, the electric sector is one of the main drivers of development, potentially signaling to public agents the need for prudent fiscal, financial, and regulatory policies to minimize the impact on reducing investment levels.

In regulated companies, the authorized cost of capital represents the risk-adjusted rate of return that investors receive for the allocated capital, thus serving as a key indicator for investment decisions, as it reflects the opportunity cost for financiers. This rate must attract investors' capital in the next regulatory period and, to do so, should be compatible with rates in other sectors of the economy (Rode & Fischbeck, 2019). For Brazilian electricity distribution companies, at each periodic tariff review cycle (CRTP), the National Electric Energy Agency (ANEEL) determines the regulatory Weighted Average Cost of Capital (WACC) to be included in the energy tariff for the subsequent four or five years in the cycles between 2003 and 2017, and in the following year starting from 2020. The regulatory WACC encompasses the cost of third-party capital and the cost of equity capital – estimated using the Capital Asset Pricing Model (CAPM) by Sharpe (1964), Lintner (1965), and Mossin (1966).

The appropriate determination of the regulatory WACC is important, as argued by Rode and Fischbeck (2019) and Bueno et al. (2022), not only from the theoretical perspective of asset pricing but also for practical reasons, that is, for companies and society: small errors or biases in defining the authorized return could, for example, result in high costs to be borne by consumers or low returns received by investors, which would discourage investment. In this sense, the choice of the method for calculating the regulatory WACC would have an impact on both investors and consumers. On one hand, an overestimated rate would allow the company to obtain additional economic gains at the expense of society; on the other, an underestimated rate would jeopardize the allocation of investment capital and the quality of the service provided, which, ultimately, would also harm consumers.

From this perspective, Aguilar et al. (2024) sought to investigate which WACC would be most appropriate for Ecuador's electric sector: one that, among those obtained from four models, would neither harm investors nor consumers. In the first model, the traditional WACC formula was used with the U.S. interest rate and market risk premium, which resulted in an overestimation due to the double

penalty of country risk and the U.S. market premium. In the second model, the market risk premium was adjusted to consider only Ecuador's specific risk premium. In the third model, the Credit Default Swap (CDS) was used to obtain the country risk premium, which was excluded from the nominal interest rate to avoid redundancy. In the fourth model, the U.S. interest rate was directly combined with the CDS to calculate the market risk premium, more accurately reflecting local economic conditions (of a dollarized economy). The results showed that, depending on the model adopted, the WACC ranged from 12.63% (model 4) to 29.70% (model 1). These authors highlight the need to adapt methodologies from developed countries for application in emerging markets, as traditional approaches overestimate the WACC. Corroborating this hypothesis, empirical evidence on the regulatory cost of capital for Brazilian electric sector distributors, such as that from Bueno et al. (2022) for the 2015-2017 triennium, suggested that the WACC was overestimated, making investments more attractive but burdening consumers.

Andrade and Martins (2017) showed that there are two groups of consumers in the Brazilian electric sector: (i) those who pay more than they should in energy tariffs, thus generating benefits for investors and losses for themselves; and (ii) those who pay less than they should, benefiting at the expense of investors. Consequently, as observed by Rocha et al. (2006) and Carvalhaes et al. (2014), there are opportunities for improvements in the modeling of the cost of capital calculation defined by ANEEL, which should allow the regulated entity to recover at least its opportunity cost of capital, including country risk, business risk, regulatory risk, and other risks specific to projects.

In other Latin American countries, a similar scenario is observed, as evidenced by Bedoya-Cadavid et al. (2023), who proposed a multifactor model to explain the variations in returns in the investment portfolio of the Colombian electric sector between 2008 and 2022. Using this model, they found a lower cost of equity capital and, consequently, a lower WACC (5.28%), compared to the one approved by the Colombian Regulatory Commission in 2019 (11.79%), indicating an overestimation of the regulated cost of capital.

In Brazil, Kayo et al. (2020) highlight ANEEL's willingness to discuss possible alternative methods for estimating the regulatory WACC. In 2018, for example, during the public consultation regarding the cost of equity capital, ANEEL presented the following options: (i) maintain the current CAPM methodology, which uses betas of U.S. companies relative to the S&P 500; (ii) maintain the CAPM but with changes to the parameters, such as using a Brazilian risk-free asset; or (iii) completely change the methodology, for instance, by applying a multifactor model. These

authors understood that ANEEL (2018) seemed to prefer the option of maintaining the CAPM with substantial parameter changes. Thus, they proposed modifications to the procedures for calculating the cost of equity capital within the CAPM framework, which provide greater stability to the beta over time and could thereby improve the policy currently used to estimate the regulatory cost of equity capital.

As reported by Simões et al. (2021), ANEEL revoked the planned WACC update for 2018, conducted Public Consultation No. 26/19, and, based on the contributions received, approved a new version of submodule 2.4 (cost of capital) of the Tariff Regulation Procedures, established an early methodological review for 2019, with implementation starting in January 2020 (ANEEL, Technical Note No. 30, 2020).

In Public Consultation No. 26/19, the following principles guided the proposed changes: i) regulatory stability – when two parameters were equally viable, the preference was to maintain the one previously applied, unless alternative options were clearly superior; ii) use of local parameters whenever possible, provided they did not compromise the theoretical foundation of the modeling; iii) simplification – when two parameters were equally viable, the simpler calculation was chosen; iv) use of public data whenever possible; v) standardization of windows for the same parameter across segments; and vi) reference periods closer to the length of the review cycles, to avoid using windows that were either too long or too short. With the new rules for calculating the WACC (ANEEL Normative Resolution No. 1,003, of February 1, 2022), ANEEL began updating the regulatory rate of return annually, through a dispatch from the Superintendency of Tariff Management.

As a result of this Consultation, in summary, the following aspects stand out: the CAPM model was adapted to use a Brazilian bond as a proxy for the risk-free interest rate – while retaining U.S. market variables for calculating the risk premium and β factor – and included a risk premium for the distribution activity; and the windows of the time series used were modified. The results of this Consultation also revealed a lack of consensus among the involved stakeholders regarding the parameters applied in the calculations of the WACC and CAPM (ANEEL, 2020). Thus, as concluded by Simões et al. (2021), the regulatory agency can benefit from evidence documented in academic studies focusing on this topic.

In addition to the new rules for calculating the WACC (ANEEL, 2020), in the first five CRTPs, implemented between 2003 and 2017, ANEEL made several modifications to the methodology for calculating the components of the WACC for Brazilian electricity distribution companies. It uses the simple arithmetic mean or the median of historical data (with different time windows, depending on the tariff component) and considers that the result obtained by these statistics represents the best future estimate for the variable. However, it should be noted that the arithmetic mean and median of historical series are only defined in

cases where the data-generating process is stationary. If the time series are not stationary, the use of these statistics for projection would be inappropriate (Greene, 2003).

Given this context, the objective of this article is to propose that projections of the components of the regulatory WACC with long time series be made using time series models, rather than the mean or median. These models are considered more appropriate as they provide a more in-depth analysis of the time series' behavior; and, in the case of non-stationarity caused by a unit root or deterministic trend, it is possible to correct it to obtain forecasts with good statistical properties, such as consistency and sufficiency.

The Emerging Markets Bond Index Plus (EMBI+), calculated by JP Morgan and used by ANEEL to represent country risk, is an example of a series that varies significantly over time: for Brazil, it reached values above 2,000 basis points around the year 2002 and fluctuated between 250 and 450 points over the last 14 years. Using the mean or median of long historical series results in the inclusion of information from different economic contexts in the calculation of the regulatory WACC, which is not adequately represented by central tendency measures. The contribution of this study lies in expanding the discussion on methods for a more appropriate determination of the regulatory WACC for Brazilian electricity distribution companies.

2 Cost of capital for regulated companies

To ensure economic balance between regulated service providers and society, governments act through regulation. Various models are used for this purpose, including the Price Cap (PC), proposed by Littlechild (1983) to regulate prices and profits of the English telecommunications monopoly. According to Camacho and Menezes (2010), the PC is an ex-ante mechanism for determining prices. As the energy tariff remains fixed for a period, the company has an incentive to reduce its operational costs to achieve higher profits. However, since regulators cannot determine prices for the entire useful life of assets (which have long lifespans), price regulation occurs, on average, every four or five years. This was the regime adopted by ANEEL to regulate the electricity sector in Brazil.

Regulatory bodies in countries define the risk-adjusted rate of return for investors (cost of capital). The Federal Energy Regulatory Commission (U.S. regulator), for example, proposed the use of the CAPM as the primary measure of risk (Bower et al., 1984). Similarly, since 2003, ANEEL has conducted several CRTPs in which the methodology used to calculate the cost of equity capital for electricity distributors was the CAPM. In the latest methodological change, implemented in 2020, this model was retained (with adaptations).

From this perspective, Haug and Wieshammer (2019)

report that electricity and gas networks in Europe generally operate under incentive regulation regimes, in which, at the beginning of each regulatory period, regulatory authorities define the authorized revenue level, including the cost of equity capital. To this end, they uniformly adopt the CAPM, which produces rates considered very low by European authorities.

In this regard, Roll and Ross (1983) found evidence that the CAPM underestimates the cost of equity capital for public utility companies compared to the Arbitrage Pricing Theory (APT). Savoia et al. (2019), when evaluating whether the implied cost of capital (ICC) model is better than the CAPM in forecasting the rate of return for Brazilian infrastructure concessionaires, also verified that the CAPM tends to underestimate the cost of equity capital. Conversely, evidence from Bower et al. (1984) showed that the CAPM overestimates the cost of equity capital for electricity and gas utilities traded on U.S. stock exchanges compared to Ross's (1976) APT; and Rode and Fischbeck (2019) suggested that the rates of return for electricity utilities were inconsistent with the CAPM used by regulators, showing a growing spread over the risk-free rate of return throughout the studied period.

The methods for estimating the cost of capital for various regulated industries in Brazil – telecommunications, electricity, gas, and rail transport – were discussed in Camacho (2004). This author highlighted two essential definitions in this process: i) the reference market to be used for estimating the parameters of the models, which, in turn, depends on the regulatory regime adopted by the sector; and ii) the financial model to be used to estimate the cost of capital. Camacho (2004) points out that the CAPM and WACC are more advantageous and predominantly used models compared to the APT and the discounted dividend model of Gordon and Shapiro (1956). Finally, he discusses the choices to be made in these models, such as defining historical windows for the use of the mean or median.

Subsequently, Camacho et al. (2006), as well as Coutinho and Oliveira (2002), recommended the use of a global CAPM adjusted to the Brazilian market (with the S&P 500 representing the market portfolio) and, contrary to the regulation in effect at the time, the adoption of the full country risk (EMBI+), rather than the partial index adopted by ANEEL. However, with this approach, Camacho et al. (2006) considered it unnecessary to add the foreign exchange risk premium. In other words, beyond systemic risk, in empirical evidence concerning the cost of equity capital for companies in emerging markets, other sources of risk, such as country risk, are added to the CAPM equation (Assaf Neto et al., 2008; Pereiro, 2002).

The methodologies for estimating the cost of capital discussed are derived from Markowitz's (1952) mean-

variance theory, which introduced the argument of the relationship between risk and return. As an extension of this model, Sharpe (1964), Lintner (1965), and Mossin (1966) developed the CAPM, which remains predominantly used for estimating the cost of equity capital for regulated entities. The CAPM, represented by Equation 1, defines the expected return of an asset – $E(R_i)$ – as a positive linear function of systemic risk (β_i).

$$E(R_i) = R_f + \beta_i (E(R_m) - R_f) \quad (1)$$

The standard procedure for estimating an asset's beta consists of regressing its historical excess return relative to the risk-free asset return ($E(R_i) - R_f$) on the market portfolio's risk premium ($E(R_m) - R_f$), as shown in Equation 2.

$$E(R_i) - R_f = \alpha_i + \beta_i (E(R_m) - R_f) + \epsilon_i \quad (2)$$

Through this procedure, the leveraged beta (β_i) is obtained, which is influenced by the company's capital structure. Using Hamada's (1972) equation, the unleveraged beta (β_u) is derived, representing only the business risk, without the effect of debt, as expressed in Equation 3.

$$\beta_u = \frac{\beta_i}{(1 + (1 - t)(D/E))} \quad (3)$$

Kayo et al. (2020) proposed a new approach to estimating the systemic risk of the Brazilian electricity distribution sector for the purpose of calculating the regulatory WACC. Within the CAPM framework, they suggest modifications to ANEEL's procedures for estimating the cost of equity capital, namely: the use of a "pure" Brazilian company as the risk asset, instead of a portfolio of U.S. energy companies; the adoption of the global CAPM concept, rather than the local CAPM – as also suggested by Rocha et al. (2006) and Assaf Neto et al. (2008); and an increase in the estimation window from 5 to 11 years. The authors argue that their proposal is based on evidence that this combination of parameters produces a more stable beta over time, while also generating fairer energy tariffs for end consumers and institutional security for investors.

To finance new investment projects, companies may also borrow funds from the financial market. Assaf Neto et al. (2008) argue that, given the interest rates in the Brazilian market, it would be difficult for a company to generate economic value. They suggest, therefore, that the cost of third-party capital be based on the U.S. market rate, plus the country risk premium, net of the tax benefit. Similarly, in calculating this cost, during the first five CRTPs, ANEEL started with the risk-free asset's return rate (R_f) and added the credit risk premium (R_c) and the country risk premium (R_b), as shown in Equation 4.

$$R_d = R_f + R_c + R_b \quad (4)$$

The combination of the costs of equity and third-party capital for companies, WACC, is obtained using Equation 5, where: W_j is the weight of the participation of the long-term capital source in the financing structure; and K_j represents the cost of each capital source (Ross et al., 2013).

$$WACC = \sum_{j=1}^n W_j \times K_j \quad (5)$$

In an analysis of the methodology for calculating the regulatory WACC used by ANEEL, Perroni (2016) suggested the following changes: (i) use of a 15-year time window to estimate the risk-free asset return; (ii) use of a 10-year time window to estimate betas, instead of 5 years; or (iii) standardization of time windows at 20 years for the components of the risk-free interest rate, beta, credit risk parameter, and country risk premium. Additionally, he proposed maintaining the assumptions: use of the WACC with the CAPM; and exclusion of foreign exchange and regulatory risks.

Lanziotti and Garcia (2018), in turn, sought to demonstrate that the regulatory WACC set by ANEEL for energy transmission companies in Brazil is below the actual costs of equity and third-party capital. These authors used data from the State Company for Electricity Generation and Transmission and the same parameters and calculation methodologies as ANEEL (CAPM and WACC models). The authors found a real WACC of 14.32%, higher than ANEEL's 6.64%. In other words, the costs estimated by ANEEL were below the actual costs borne by the analyzed company.

Simões et al. (2021), from a critical-analytical perspective, sought to examine ANEEL's methodological approach to calculating the WACC, suggesting possible improvements for future tariff reviews, including: i) reconsidering the sample of U.S. electricity companies used in calculating the beta factor, as it does not reflect the situation of the Brazilian energy transmission market; ii) considering options to simplify the calculation of the CAPM beta factor; iii) excluding companies with missing data from the sample when determining the weights of U.S. companies in calculating the unleveraged beta; iv) using a theoretical basis to define the periods of the data series for the parameters used in the WACC calculation; and v) calculating the costs of equity and debt based on data from the same period, rather than lagged data.

With this discussion in mind, this study proposes a change in the method for obtaining ANEEL's regulatory WACC, which will be described below.

3 Methodological procedures

3.1 Data and variables

To compare the results obtained in this analysis with those of ANEEL, it was decided to use the same database employed by the agency in calculating the regulatory WACC during the first five CRTPs (2003 to 2017), which is available on its website. The periodicities of the variables used are presented in Table 1. It is important to note that all variables, regardless of the frequency at which the data were collected (daily or monthly), are presented on an annual basis (equivalent rate).

Table 1

Periodicity of the series used by ANEEL in calculating tariff components

CRTP	Reference	Period	Duration (years)
Historical series	UST10	oct/1984 - sep/2017	33
1 st		mar/1995 - jun/2002	7
2 nd		mar/1995 - jun/2006	11
3 rd		jan/1995 - dec/2010	16
4 th		oct/1984 - sep/2014	30
5 th		oct/1987 - sep/2017	30
Historical series	S&P500	oct/1984 - sep/2017	33
1 st		1926 - 2000	74
2 nd		1928 - 2006	78
3 rd		1928 - 2010	82
4 th		oct/1984 - sep/2014	30
5 th		oct/1987 - sep/2017	30
Historical series	EMBI+	apr/1994 - jul/2018	24
1 st		apr/1994 - aug/2002	8
2 nd		apr/1994 - jun/2006	12
3 rd		jan/2000 - dec/2010	11
4 th		oct/1999 - sep/2014	15
5 th		oct/2003 - sep/2017	14
Historical series	CPI	jan/1948 - jun/2018	70
1 st		feb/1995 - dec/2002	12
2 nd		jan/1995 - dec/2006	16
3 rd		jan/1995 - dec/2010	20
4 th		jan/1995 - dec/2014	24
5 th		sep/2003 - dec/2017	14

Source: Prepared by the authors.

For the calculation of the regulatory WACC, ANEEL used the following variables:

i) UST10 – return rate of the ten-year U.S. Treasury note (arithmetic mean based on different time windows).

ii) S&P500 – return rate of the Standard and Poor's 500 index (arithmetic mean).

In calculating the arithmetic means of UST10 and S&P500, there was a trend toward standardizing the time series length (30 years) in the last two CRTPs.

iii) Beta – to obtain this variable, ANEEL calculates the leveraged betas of U.S. companies (benchmark); unlevers them according to Hamada's (1972) model; and re-levers them based on the capital structure of Brazilian companies. To calculate the beta, ANEEL standardized a five-year time window starting from the second CRTP.

iv) EMBI+ – country risk indicator for Brazil.

v) CPI – U.S. inflation rate calculated based on the past twelve months (annual).

vi) Global credit rating – credit risk parameter for electricity distributors assigned by Moody's.

Table 2 presents the data on the components used, the proportion of each funding source in the capital structure, and the regulatory WACC adopted by ANEEL in the first five CRTPs. Due to mergers, acquisitions, and consolidations of U.S. companies, ANEEL evaluated, in each CRTP, the companies to be used as benchmarks for calculating the beta. As a result, it became unfeasible to regress the returns of a single group of U.S. companies against the S&P500 return. For this reason, this component could not be obtained using the time series models proposed here.

Table 2

Composition of the regulatory WACC adopted by ANEEL in the first five CRTPs

Variable	1 st CRTP	2 nd CRTP	3 rd CRTP	4 th CRTP	5 th CRTP
Nominal Cost of Equity Capital (R\$)	17.46%	15.82%	13.43%	13.58%	11.65%
Real Cost of Equity Capital (R\$)	14.71%	12.88%	10.72%	10.90%	9.57%
Market Risk Premium	7.76%	6.09%	5.82%	7.56%	6.58%
Risk-Free Asset Return Rate	6.01%	5.32%	4.87%	5.64%	4.94%
Market Portfolio Return Rate	13.77%	11.41%	10.69%	13.20%	11.52%
Final Beta	0.69	0.773	0.741	0.703	0.640
Leveraged Beta	0.26	0.555	0.741	0.703	0.640
Unleveraged Beta	0.15	0.295	0.410	0.432	0.393
IRPJ + CSLL	34%	34%	34%	34%	34%
Beta Adjustment (Regulatory Risk)	0.42	0.21	0.00	0.00	0.00
Brazil Risk Premium	4.08%	4.01%	4.25%	2.62%	2.50%
Foreign Exchange Risk Premium	2.00%	1.78%	0.00%	0.00%	0.00%
U.S. Inflation Rate	2.40%	2.60%	2.45%	2.41%	1.90%
Nominal Cost of Third-Party Capital (R\$)	15.76%	14.07%	11.26%	11.63%	11.88%
Real Cost of Third-Party Capital (R\$)	8.61%	7.38%	5.68%	5.94%	6.47%
Risk-Free Rate	6.01%	5.32%	4.87%	5.64%	4.94%
Brazil Risk Premium	4.08%	4.01%	4.25%	2.62%	2.50%
Credit Risk	3.67%	2.96%	2.14%	3.37%	4.44%
Foreign Exchange Risk Premium	2.00%	1.78%	0.00%	0.00%	0.00%
Capital Structure					
Proportion of Equity Capital	50.00%	42.84%	45.00%	51.24%	51.24%
Proportion of Third-Party Capital	50.00%	57.16%	55.00%	48.76%	48.76%
Nominal WACC (R\$)	16.61%	14.82%	12.24%	12.63%	11.76%
Real WACC (R\$)	11.66%	9.74%	7.94%	8.48%	8.06%

Source: Prepared by the authors.

3.2 Data analysis method

The values of ANEEL's regulatory WACC were compared to the values obtained in this study after forecasting, using time series models (estimated with 5% significance), the tariff components UST10, S&P 500, EMBI+, and CPI with data from the series covering periods between 1984 and 2023 (Technical Note No. 55/2024-STR/ANEEL, 2024). In the forecasts, univariate time series models were used following the method of Box et al. (2015), which consisted of: i) testing the stationarity of the series; ii) transforming series with non-stationary behavior; iii) projecting these tariff components; iv) recalculating the regulatory WACC for the first five CRTPs using the projected values of the variables; and v) comparing the proposed regulatory WACC with that of ANEEL in the first five CRTPs.

The stationarity of the series was evaluated using the three methods suggested by Gujarati and Porter (2011), which are: i) graphical analysis; ii) correlogram test; and iii) unit root test. The presence of a unit root was tested using the following tests: ADF by Dickey and Fuller (1979), PP by Phillips and Perron (1988), and KPSS by Kwiatkowski et al. (1992). In the ADF and PP tests, the null hypothesis assumes the existence of a unit root (non-stationarity); in the KPSS test, the null hypothesis assumes the absence of a unit root (stationarity).

4 Results Analysis

4.1 Graphical analysis

Figure 1 presents the series for UST10 (Panel A), S&P500 (Panel B), EMBI+ (Panel C), and CPI (Panel D) from 1984 to 2023. In Panel A, a downward trend in UST10 returns is observed (indicating non-stationarity), dropping from a level of 12% per year to 2% per year. In Panel B, it is noted that the S&P500 series does not show a defined trend. In Panel C, it is observed that the EMBI+ series: (i) reached a peak of 2,436 points in 2002; (ii) fell to 500 points in 2004; (iii) fluctuated between 150 and 600 points in 2008; and (iv) dropped to a level of 300 points after that period. The variability of EMBI+ was higher in the period from 1995 to 2005 compared to 2005 to 2018, suggesting non-stationarity. In Panel D, it is observed that the CPI series did not show a defined trend, suggesting stationary behavior. The average inflation was 3.52% per year, with a median of 2.86% per year and a maximum of 14% per year (1980s).

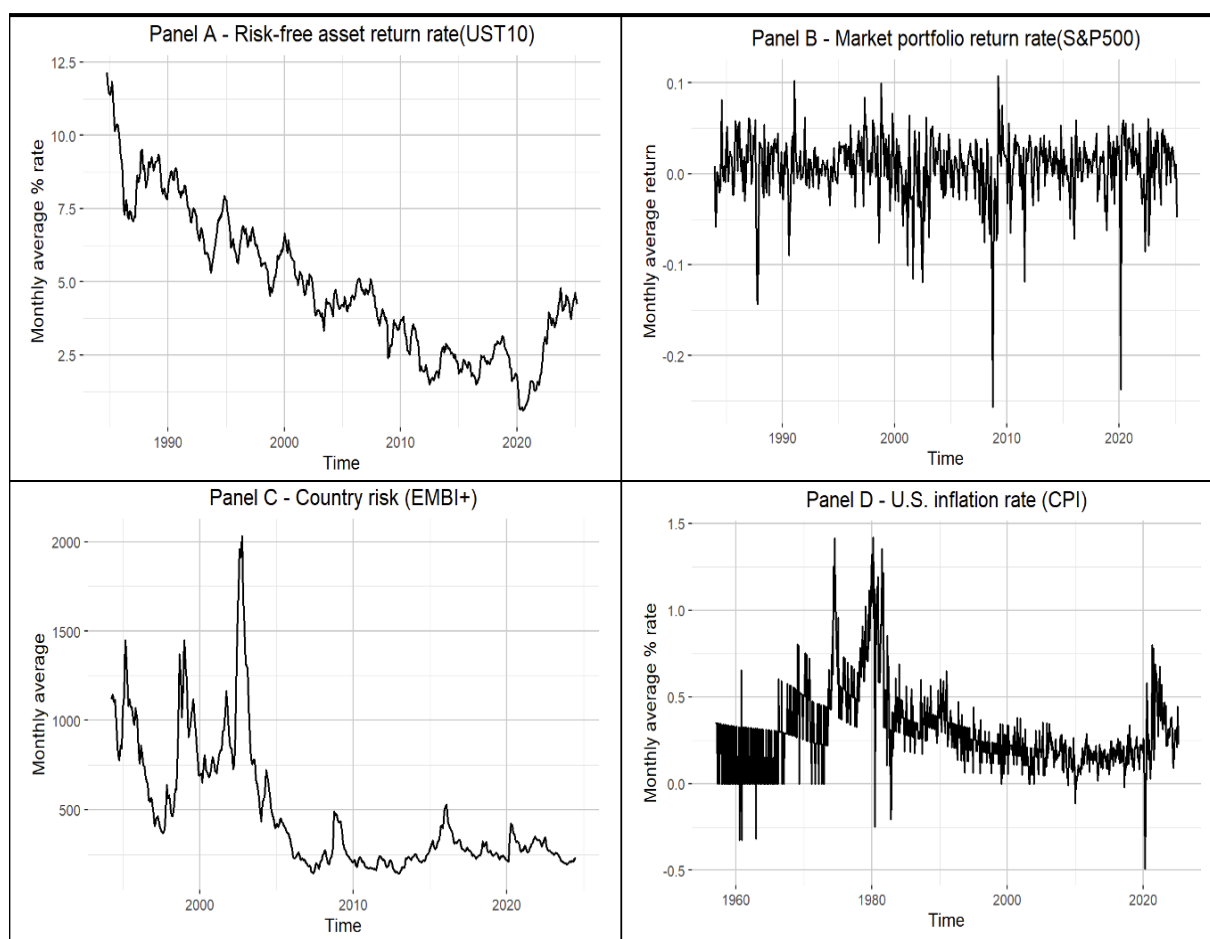


Figure 1. Time series of the tariff components UST10, S&P500, EMBI+, and CPI
Source: Prepared by the authors.

4.2 Autocorrelation function analysis

In Figure 2, Panel A, the autocorrelation function of the UST10 series is presented. It is observed that its decay is extremely slow, meaning that shocks to the series do not dissipate over time. Processes with this characteristic are generally non-stationary. In Panel B, the autocorrelation function of the S&P500 series shows an exponential decay pattern, which is an indication of stationarity. In Panel C, it is verified that the autocorrelation function of the EMBI+ series exhibits behavior consistent with non-stationary processes. In

Panel D, it is noted that the autocorrelation function of the CPI index also displays behavior characteristic of a non-stationary process.

The presence of a deterministic trend induces a behavior in the autocorrelation function very similar to that of series with unit roots. In this case, first differencing is not the most appropriate procedure to address the issue of non-stationarity (Hamilton, 1994). Therefore, it is necessary to test whether the non-stationary behavior indicated by the autocorrelation functions is confirmed by unit root tests.

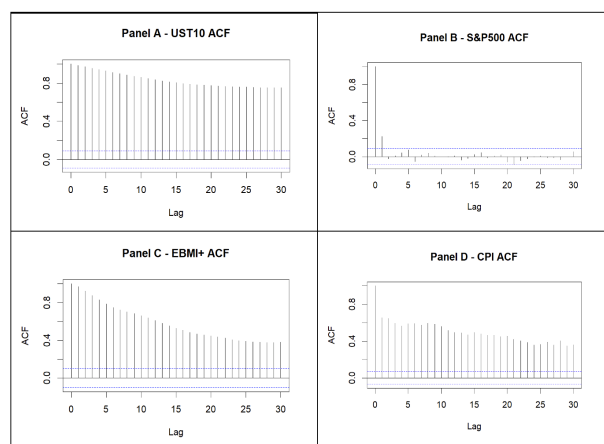


Figure 2. Autocorrelation functions of the tariff components UST10, S&P500, EMBI+, and CPI.
Source: Prepared by the authors.

4.3 Unit root tests

To test whether the analyzed financial series exhibit a unit root, the ADF, PP, and KPSS tests were conducted in three modalities: i) without constant and trend; ii) with constant and without trend; and iii) with constant and trend.

4.3.1 ADF Test

Table 3 presents the results of the ADF test for the UST10, S&P500, EMBI+, and CPI series. The selection of the number of lags for the test, implemented using the `adf.test` command from the R statistical pac

For the UST10 series, the p-values are less than or equal to 5% in most cases. When the test is conducted with a constant and without a trend, the p-values are high, reaching 24%. The figure for this series (see Panel A of Figure 1) had suggested the presence of a negatively sloped trend. In such cases, the most appropriate ADF test result is the one conducted with a constant and trend, where the null hypothesis of a unit root is rejected. The non-stationarity indicated by the autocorrelation function is likely due to the presence of a deterministic trend in the series. For the S&P500, the p-values are around 1% in all three test types, and thus, the null hypothesis of a unit root is rejected. The series is stationary, as also suggested by the autocorrelation function figure (see Panel B of Figure 2). For the EMBI+, the tests: i) with a constant and without a trend; and ii) with a constant and trend indicate the presence of a unit root. However, it is not possible to assert that the series exhibits a clear trend. Sensoy et al. (2017), for example, analyzed the Brazilian EMBI+ series and rejected the null hypothesis of a unit root. Finally, for the CPI index series, the p-values associated with most tests allow the rejection of the null hypothesis of a unit root at a 5% significance level.

Table 3

ADF Test for the tariff components UST10, S&P500, EMBI+, and CPI

UST10								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	ADF	p-value	Lag	ADF	p-value	Lag	ADF	p-value
0,00	-2.89	0.01	0,00	-2.56	0.10	0,00	-4.48	0.01
1,00	-2.22	0.03	1,00	-2.24	0.23	1,00	-5.05	0.01
2,00	-2.48	0.01	2,00	-2.30	0.21	2,00	-4.69	0.01
3,00	-2.30	0.02	3,00	-2.22	0.24	3,00	-4.95	0.01
4,00	-2.38	0.02	4,00	-2.35	0.19	4,00	-5.32	0.01
5,00	-2.65	0.01	5,00	-2.57	0.10	5,00	-5.53	0.01

S&P500								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	ADF	p-value	Lag	ADF	p-value	Lag	ADF	p-value
0,00	-3.50	0.00	0,00	-4.06	0.01	0,00	-4.06	0.01
1,00	-3.40	0.00	1,00	-3.89	0.01	1,00	-3.90	0.01
2,00	-3.50	0.00	2,00	-4.04	0.01	2,00	-4.04	0.01
3,00	-4.10	0.00	3,00	-4.78	0.01	3,00	-4.77	0.01
4,00	-4.10	0.00	4,00	-4.78	0.01	4,00	-4.77	0.01
5,00	-4.20	0.00	5,00	-4.95	0.01	5,00	-4.94	0.01

EMBI+								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	ADF	p-value	Lag	ADF	p-value	Lag	ADF	p-value
0,00	-2.60	0.01	0,00	-2.92	0.05	0,00	-3.07	0.13
1,00	-2.57	0.01	1,00	-2.90	0.05	1,00	-3.07	0.13
2,00	-2.08	0.04	2,00	-2.18	0.25	2,00	-2.19	0.50
3,00	-2.17	0.03	3,00	-2.34	0.19	3,00	-2.39	0.41
4,00	-2.10	0.04	4,00	-2.23	0.23	4,00	-2.27	0.46
5,00	-2.10	0.04	5,00	-2.23	0.23	5,00	-2.27	0.46
6,00	-2.08	0.04	6,00	-2.20	0.25	6,00	-2.22	0.48
7,00	-2.03	0.04	7,00	-2.12	0.28	7,00	-2.13	0.52
8,00	-2.08	0.04	8,00	-2.20	0.25	8,00	-2.22	0.48
9,00	-2.22	0.03	9,00	-2.39	0.17	9,00	-2.43	0.39

CPI								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	ADF	p-value	Lag	ADF	p-value	Lag	ADF	p-value
0,00	-2.12	0.03	0,00	-2.70	0.08	0,00	-2.64	0.30
1,00	-2.19	0.03	1,00	-3.29	0.02	1,00	-3.29	0.07
2,00	-2.65	0.01	2,00	-3.79	0.01	2,00	-3.76	0.02
3,00	-2.79	0.01	3,00	-3.97	0.01	3,00	-3.94	0.01
4,00	-2.72	0.01	4,00	-3.94	0.01	4,00	-3.91	0.01
5,00	-2.89	0.01	5,00	-4.21	0.01	5,00	-4.18	0.01
6,00	-2.87	0.01	6,00	-4.31	0.01	6,00	-4.29	0.01

Note: UST10 is the return rate of the ten-year U.S. Treasury note; S&P 500 is the return rate of the Standard and Poor's 500 index; EMBI+ is the country risk indicator for Brazil; and CPI is the U.S. inflation rate calculated based on the past twelve months.

Source: Prepared by the authors.

4.3.2 PP Test

Table 4 presents the results for the PP test, which adjusts the test statistic to account for the presence of heteroscedasticity, a common characteristic in financial series. The selection of lags for the analyzed series was based on the AIC. For the UST10, it is only possible to reject the null hypothesis of a unit root when the PP test is conducted with a constant and trend. For the S&P500, the null hypothesis of a unit root is rejected for all types of tests performed. For the EMBI+, the null hypothesis of a unit root is rejected, with 5% significance, when the test is conducted without a constant and trend. Finally, for the CPI series, it is possible to reject the null hypothesis of a unit root, with 5% significance, for all three types of tests.

Table 4
PP Test for the tariff components UST10, S&P500, EMBI+, and CPI

UST10								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	PP	p-value	Lag	PP	p-value	Lag	PP	p-value
5,00	-2.54	0.36	5,00	-5.88	0.41	5,00	-38.51	0.01
S&P500								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	PP	p-value	Lag	PP	p-value	Lag	PP	p-value
5,00	-28.67	0.01	5,00	-38.61	0.01	5,00	-38.77	0.01
EMBI+								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	PP	p-value	Lag	PP	p-value	Lag	PP	p-value
10,00	-8.03	0.05	10,00	-10.66	0.14	10,00	-12.24	0.36
CPI								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	PP	p-value	Lag	PP	p-value	Lag	PP	p-value
6,00	-10.57	0.02	6,00	-23.18	0.01	6,00	-23.07	0.04

Source: Prepared by the authors.

4.3.3 KPSS Test

According to the results presented in Table 5, the UST10, S&P500, EMBI+, and CPI series are stationary, as the p-values for the three types of KPSS tests are greater than or equal to 10%: the null hypothesis of stationarity is not rejected. The selection of the number of lags was based on the AIC.

Table 5
KPSS Test for the tariff components UST10, S&P500, EMBI+, and CPI

UST10								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	KPSS	p-value	Lag	KPSS	p-value	Lag	KPSS	p-value
4,00	0,14	0,10	4,00	0,16	0,10	4,00	0,03	0,10
S&P500								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	KPSS	p-value	Lag	KPSS	p-value	Lag	KPSS	p-value
4,00	0,98	0,10	4,00	0,04	0,10	4,00	0,04	0,10
EMBI+								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	KPSS	p-value	Lag	KPSS	p-value	Lag	KPSS	p-value
15,00	0,82	0,10	15,00	0,16	0,10	15,00	0,12	0,10
CPI								
Without constant and trend			With constant, without trend			With constant and trend		
Lag	KPSS	p-value	Lag	KPSS	p-value	Lag	KPSS	p-value
6,00	0,24	0,10	6,00	0,09	0,10	6,00	0,10	0,10

Source: Prepared by the authors.

4.4 Series transformation

Although the ADF, PP, and KPSS tests did not confirm the presence of a unit root in the UST10 series, it exhibits an autocorrelation function consistent with non-stationary processes. In this case, the non-stationary behavior is likely induced by the presence of a deterministic trend, which needs to be estimated and subtracted from the series. Equation 6 expresses the estimated trend for this series, with the respective p-values of the coefficients:

$$UST10_t = 8.65 - 0.015t \quad (6)$$

In Figure 3, Panel A, the UST10 series is shown after the trend extraction (henceforth referred to as the

transformed UST10 series), and in Panel B, its respective autocorrelation function. The signs of non-stationarity, detected by the autocorrelation function in Figure 2, have disappeared.

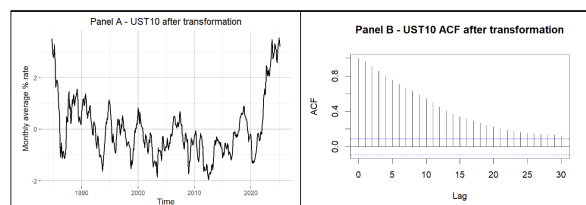


Figure 3. Transformed UST10 series and the autocorrelation function after extraction of the deterministic trend
Source: Prepared by the authors.

For the EMBI+, the KPSS test statistic allows the rejection of the null hypothesis of a unit root; in the PP and ADF tests, the null hypothesis is rejected only in the versions without a constant and linear trend. The series shows a decay over time and stabilizes around approximately 200 points, so it is possible to infer the existence of an exponential trend with a horizontal asymptote. The estimated exponential trend for the EMBI+ series (Equation 7) is illustrated in Figure 4.

$$EMBI+_t = 6.71 \cdot \exp(t^{0.004}) \quad (7)$$

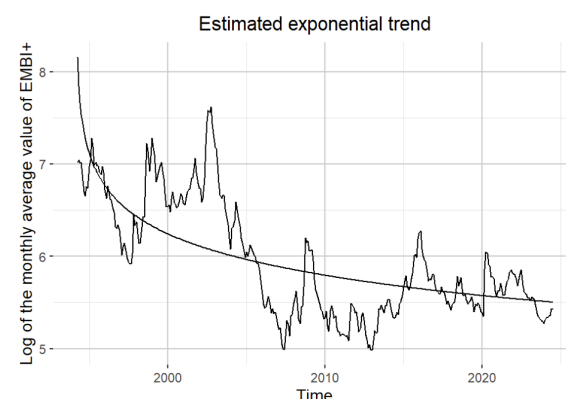


Figure 4. Estimated exponential trend for the EMBI+ series
Source: Prepared by the authors.

In Figure 5, the EMBI+ series is shown after the extraction of the exponential trend (Panel A); and the autocorrelation function of the transformed series (Panel B).

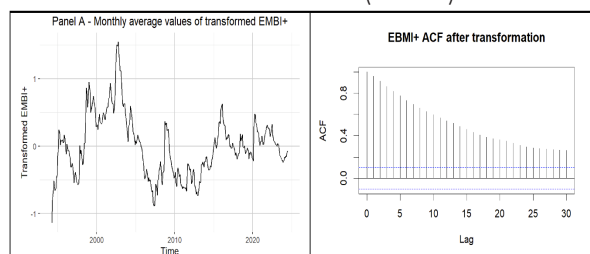


Figure 5. Transformed EMBI+ series and autocorrelation function after trend extraction
Source: Prepared by the authors.

4.5 Estimated time series models

The partial autocorrelation function (PACF), together with the autocorrelation function, provides indications of the type of ARMA model and the lag orders that should be fitted for each series. The AIC criterion was used to select the models. In Figure 6, the PACFs of the transformed UST10, S&P500, transformed EMBI+, and CPI series are presented.

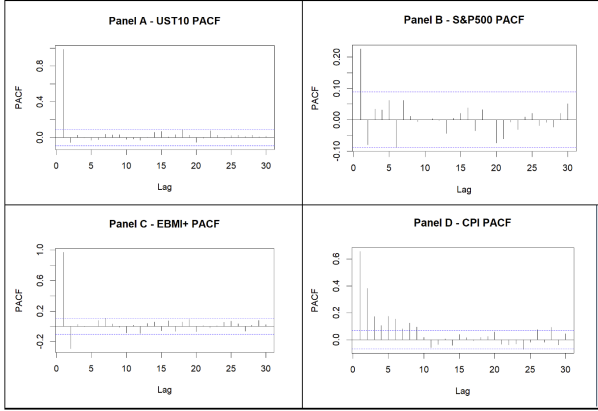


Figure 6. Partial autocorrelation of the transformed UST10, S&P500, transformed EMBI+, and CPI series
Source: Prepared by the authors.

The models were estimated within each of ANEEL's CRTPs using the data provided by ANEEL on its website. For the transformed UST10, the partial autocorrelation function indicates that the most appropriate model is an AR(2). The choice of the autoregressive order was made using the AIC criterion. Equations 8 to 12 represent, respectively, the models for UST10 in CRTPs 1 to 5.

$$UST10Trans_t = -1,084UST10Trans_{t-1} - 0,504UST10Trans_{t-2} + \epsilon_t + 0,726\epsilon_{t-1} \quad (8)$$

$$UST10Trans_t = -1,084UST10Trans_{t-1} - 0,504UST10Trans_{t-2} + \epsilon_t + 0,726\epsilon_{t-1} \quad (9)$$

$$UST10Trans_t = -1,008UST10Trans_{t-1} - 0,499UST10Trans_{t-2} + \epsilon_t + 0,613\epsilon_{t-1} \quad (10)$$

$$UST10Trans_t = 1,333UST10Trans_{t-1} - 0,567UST10Trans_{t-2} + \epsilon_t + 0,882\epsilon_{t-1} + 0,590\epsilon_{t-2} \quad (11)$$

$$UST10Trans_t = 1,401UST10Trans_{t-1} - 0,606UST10Trans_{t-2} + \epsilon_t - 0,888\epsilon_{t-1} + 0,533\epsilon_{t-2} \quad (12)$$

For the original S&P500 series, the partial autocorrelation function indicates that the number of lags to be used is equal to 1. The use of the AIC criterion for selecting the lag order in the estimated models, which are represented by Equations 13 to 17, respectively, resulted in different models for each CRTP. This behavior is attributed to the variation in the time window used by ANEEL: (i) 1st CRTP, 10/15/1984 to 06/15/2000; (ii) 2nd CRTP, 03/15/1995 to 06/15/2006; (iii) 3rd CRTP, 03/15/1995 to 12/15/2010; (iv) 4th CRTP, 10/15/1984 to 09/15/2014; and (v) 5th CRTP, 10/15/1987 to 09/15/2017. In the 1st, 4th, and 5th CRTPs, when ANEEL uses all available observations from 1984 to calculate the component, the estimated models are of the ARMA(2,2) type; and the change in parameters

is due to the increased number of observations, which improved the estimation. Equations 13 to 17 represent, respectively, the models for the S&P500 in CRTPs 1 to 5.

$$S\&P500_t = -0,962S\&P500_{t-1} - 0,383S\&P500_{t-2} + \epsilon_t + 0,589\epsilon_{t-1} - 0,151\epsilon_{t-2} \quad (13)$$

$$S\&P500_t = -0,347S\&P500_{t-1} + \epsilon_t \quad (14)$$

$$S\&P500_t = 0,946922S\&P500_{t-1} + \epsilon_t \quad (15)$$

$$S\&P500_t = 1,333S\&P_{t-1} - 0,567S\&P500_{t-2} + \epsilon_t - 0,882\epsilon_{t-1} + 0,590\epsilon_{t-2} \quad (16)$$

$$S\&P500_t = 1,401S\&P_{t-1} - 0,606S\&P500_{t-2} + \epsilon_t - 0,888\epsilon_{t-1} + 0,533\epsilon_{t-2} \quad (17)$$

Based on the ADF test, it was not possible to reject the null hypothesis of a unit root for the observations of the EMBI+ series used in the first two CRTPs. Therefore, the first difference of this series was taken for these periods. Equations 18 to 22 represent, respectively, the models for this series in CRTPs 1 to 5.

$$EMBI +_t = 0,917EMBI +_{t-1} + \epsilon_t \quad (18)$$

$$EMBI +_t = 0,347 + 0,944EMBI +_{t-1} + \epsilon_t \quad (19)$$

$$EMBI +_t = 0,186 + 0,960EMBI +_{t-1} + \epsilon_t \quad (20)$$

$$EMBI +_t = 0,135 + 0,969EMBI +_{t-1} + \epsilon_t \quad (21)$$

$$EMBI +_t = 0,132 + 0,969EMBI +_{t-1} + \epsilon_t \quad (22)$$

For the CPI, it is observed that the PACF shows a significant peak at lag 1, followed by a minimized wave that alternates between positive and negative correlations. This behavior is indicative of a moving average term in the data.

The estimated models are expressed by Equations 23 to 27, corresponding, respectively, to CRTPs 1 to 5. A variation in the type of estimated model is observed, for example, ARMA(2,1) for the 1st CRTP and ARMA(1,1) for the 2nd CRTP. Once again, there was variation in the time window used by ANEEL.

$$CPI_t = 0,003 + 0,377CPI_{t-1} - 0,518CPI_{t-2} + \epsilon_t + 0,817\epsilon_{t-1} \quad (23)$$

$$CPI_t = 0,850CPI_{t-1} + \epsilon_t + 0,507\epsilon_{t-1} \quad (24)$$

$$CPI_t = 0,203CPI_{t-1} - 0,585CPI_{t-2} + \epsilon_t + 1,529\epsilon_{t-1} + 0,809\epsilon_{t-2} \quad (25)$$

$$CPI_t = 0,125CPI_{t-1} - 0,596CPI_{t-2} + \epsilon_t + 1,379\epsilon_{t-1} + 0,627\epsilon_{t-2} \quad (26)$$

$$CPI_t = 0,935CPI_{t-1} + \epsilon_t \quad (27)$$

4.6 Comparison of the proposed regulatory WACC with the one calculated by ANEEL

The values of the variables UST10, S&P500, EMBI+, and CPI were estimated using the time series models described in the previous section. For the other components of

the regulatory WACC, the same values used by ANEEL for each CRTP were adopted. Thus, it was possible to compare the impact of the change in methodology for estimating these variables on the cost of capital.

Table 6 presents the values, those proposed in this study and those adopted by ANEEL, for each tariff component and for the regulatory WACC. For the 1st CRTP, the proposed WACC is considerably higher than the WACC adopted by ANEEL, a difference mainly caused by the higher estimated value for the EMBI+.

Table 6

Comparison of the proposed UST10, S&P500, EMBI+, CPI components, and WACC

CRTP	1 st CRTP	2 nd CRTP	3 rd CRTP	4 th CRTP	5 th CRTP	Mean
(a)						
ANEEL Component	5.09%	4.11%	3.00%	2.08%	1.35%	4.21%
(b)						
Proposed Component	3.68%	3.57%	3.17%	2.09%	2.26%	2.96%
(a) – (b)	-1.41%	-0.54%	0.17%	0.01%	0.91%	-1.25%
S&P500						
(a)						
ANEEL Component	9.33%	5.86%	21.56%	18.51%	17.21%	12.12%
(b)						
Proposed Component	9.96%	15.11%	18.40%	10.50%	15.02%	13.80%
(a) – (b)	0.63%	9.25%	-3.16%	-8.01%	-2.19%	1.68%
EMBI+						
(a)						
ANEEL Component	7.34%	2.83%	1.90%	2.24%	2.65%	3.49%
(b)						
Proposed Component	7.06%	2.77%	1.88%	2.16%	2.57%	4.50%
(a) – (b)	-0.2%	-0.06%	-0.2%	-0.08%	-1.01%	0.08%
CPI						
(a)						
ANEEL Component	1.82%	4.04%	2.04%	1.74%	2.04%	2.35%
(b)						
Proposed Component	2.00%	1.37%	1.12%	1.59%	2.00%	1.62%
(a) – (b)	0.18%	-2.67%	-0.92%	-0.15%	-0.04%	-0.73%
WACC						
(a)						
ANEEL Component	11.66%	9.74%	7.94%	8.48%	8.06%	9.18%
(b)						
Proposed Component	12.05%	10.23%	8.94%	6.24%	7.82%	9.05%
(a) – (b)	0.39%	0.49%	1.00%	-2.25%	-0.24%	-0.12%

Source: Prepared by the authors.

In the 2nd CRTP, the proposed WACC was similar to ANEEL's WACC, despite the differences in the components recalculated in this study. For the 3rd CRTP, the higher estimated value for the S&P500 increased the proposed WACC by 0.97% compared to ANEEL's WACC. For the 4th and 5th CRTPs, the proposed WACC was lower than ANEEL's WACC due to the lower estimated values for the UST10 component.

It was generally observed that the estimated time series models resulted in values different from those calculated by ANEEL in the CRTPs. The adoption of ARMA-type models for the projection of UST10 generated lower values

in the 1st and 2nd CRTPs and higher values in the 3rd, 4th, and 5th CRTPs. The average difference was -1.25%. Thus, this would imply a reduction in the regulatory WACC in the 1st and 2nd CRTPs and an increase in the 3rd, 4th, and 5th CRTPs. Considering the average, there would be a reduction in the set of WACC values.

For the S&P500 series, the differences between the values obtained by the ARMA models and those calculated by ANEEL showed significant variability: in the 1st CRTP, the forecasted value was 0.63% above ANEEL's calculated value; in the 2nd CRTP, the forecasted value was 9.25 percentage points above ANEEL's calculated value; in the subsequent CRTPs, the proposed values were below those calculated by ANEEL: 3rd CRTP, -3.16%; 4th CRTP, -8.01%; and 5th CRTP, -2.19%.

For the EMBI+ series, the values estimated by the ARMA model were: 7.06; 2.76; 1.88; 2.17; and 2.57, respectively, for the 1st, 2nd, 3rd, 4th, and 5th CRTPs. These values were very close to those presented by ANEEL. The largest difference was in the 5th CRTP: the proposed EMBI+ was 1% higher than the value calculated by ANEEL.

The values estimated by the ARMA models for the CPI series from the 1st to the 5th CRTPs were, respectively, 2%; 1.37%; 1.12%; 1.59%; and 2%. The largest difference occurred in the 2nd CRTP, where the proposed CPI value was 2.67% below the value calculated by ANEEL. The average predicted value (average across the 5 CRTPs) by the ARMA model was 1.62%, while the average of the values calculated by ANEEL was 2.35%.

The difference between the values of the components estimated in this study and those adopted by ANEEL produced different results for the regulatory WACC. For the 1st CRTP, the proposed WACC (12.05%) is very close to that considered by ANEEL (11.66%). For the 2nd CRTP, the proposed WACC (10.23%) was also similar to ANEEL's WACC (9.74%), despite the differences in the recalculated components in this study. For the 3rd CRTP, the higher estimated value for the S&P500 increased the proposed WACC (8.94%) by 1% compared to ANEEL's WACC (7.94%). For the 4th and 5th CRTPs, the proposed WACC values were lower as a result of lower estimated values for the S&P500. These findings corroborate the hypotheses that the regulatory WACC for the electric sector in Latin American countries may be overestimated, as seen in the studies by Bueno et al. (2022), Bedoya-Cadavid et al. (2023), and Aguilar et al. (2024).

However, overall, despite the differences observed between the proposed WACC and ANEEL's WACC, the average WACC for the five CRTPs indicates a value lower by only 0.12%. The average proposed WACC was 9.05%, while the average ANEEL WACC was 9.18%.

5 Final Considerations

The focus of this study was to propose that the estimation of tariff components with long time series used in calculating the regulatory WACC for Brazilian electricity distribution companies be conducted using time series models, rather than the simple arithmetic mean and median adopted by ANEEL in the first five CRTPs.

ANEEL's role is to seek balance and efficiency in the infrastructure of the Brazilian electricity system. On one hand, estimating the regulatory WACC above the appropriate rate to compensate for the risk of this type of business would imply a transfer of wealth from consumers to investors. On the other hand, estimating the cost of capital below a return rate consistent with the risk would result in extracting economic gains from investors. Such an outcome would send a negative signal to the market, deterring capital flows to these assets and, in the long term, reducing the availability of resources for investment in the expansion and improvement of distribution networks. Therefore, the accurate estimation of the regulatory WACC has significant consequences for the market and society.

Of the seven components with long time series used in calculating the regulatory WACC in the first five CRTPs, four were considered in this study: UST10, S&P500, EMBI+, and CPI. As the regulatory and foreign exchange risk premiums were not included by ANEEL in the WACC calculations starting from the 3rd CRTP, the methodology proposed here was not applied to these components. The systemic risk, represented by the beta, could also not be obtained using the proposed method because the group of U.S. companies used as a reference for its calculation was changed by ANEEL in each CRTP.

The proposed method comprised five stages, which consisted of: testing the stationarity of the series; transforming non-stationary series into stationary ones; projecting the tariff components using time series models; calculating the WACC for Brazilian electricity distribution companies based on these components estimated by time series; and comparing the proposed regulatory WACC with that of ANEEL.

It was generally observed that the estimated time series models resulted in values different from those calculated by ANEEL for the tariff components in the first five CRTPs. Consequently, a reduction in the regulatory WACC was verified in the 1st and 2nd CRTPs and an increase in the 3rd, 4th, and 5th CRTPs. On average, the WACC values obtained by the method proposed here are lower than those of ANEEL. However, although there are differences between the proposed WACC and ANEEL's WACC, the average for the five CRTPs indicates a value quite close.

Based on the results of this study, an important recommendation for calculating the WACC is that all

observed values for each series should always be used. The parameters of the ARMA models and even the mean estimator tend toward their true value as the sample size increases. Changing the time window can introduce bias in the estimations and, consequently, increase the underlying uncertainty in the expectations of market agents involved regarding the WACC that may be adopted by ANEEL.

As a continuation of this proposal, two methodological paths are suggested: deepening research into the use of time series models as an alternative for projecting the long time series that make up the regulatory WACC, and considering other models for calculating the cost of equity capital.

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