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Policies Towards Energy Poverty Reduction Goal: Role of Female Political Participation and Financial Globalization

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Abstract

The United Nations Sustainable Development Goals (SDGs) emphasize the importance of energy by making affordable and clean fuel access the focus of Goal 7. Energy poverty is a widespread issue globally, particularly in developing countries. Thus, this investigation inspects the drivers of energy poverty in Brazil using data from 1997Q1 to 2022Q4. The study introduces the wavelet Zivot–Andrews (WZA) unit root test, which modifies the traditional Zivot–Andrews (ZA) test by incorporating wavelet analysis, allowing decomposition of the time series into different time scales (short-term, medium-term and long-term). This enables the WZA test to capture structural breaks and unit roots more effectively across various time scales. In addition, the study employs wavelet quantile-on-quantile regression. The results show that across all quantiles and time scales, an increase in financial globalization and economic policy uncertainty increases energy poverty. The study also shows that female political participation increases energy poverty in the short and long term. In contrast, in the medium term and across all quantiles, female political participation decreases energy poverty. Lastly, an increase in financial development decreases energy poverty across all quantiles and periods. Based on these findings, policies are suggested.

Keywords: Energy poverty, economic policy uncertainty, female political participation, financial globalization, financial development

JEL Classification: C22, D72, F65, O13, Q48

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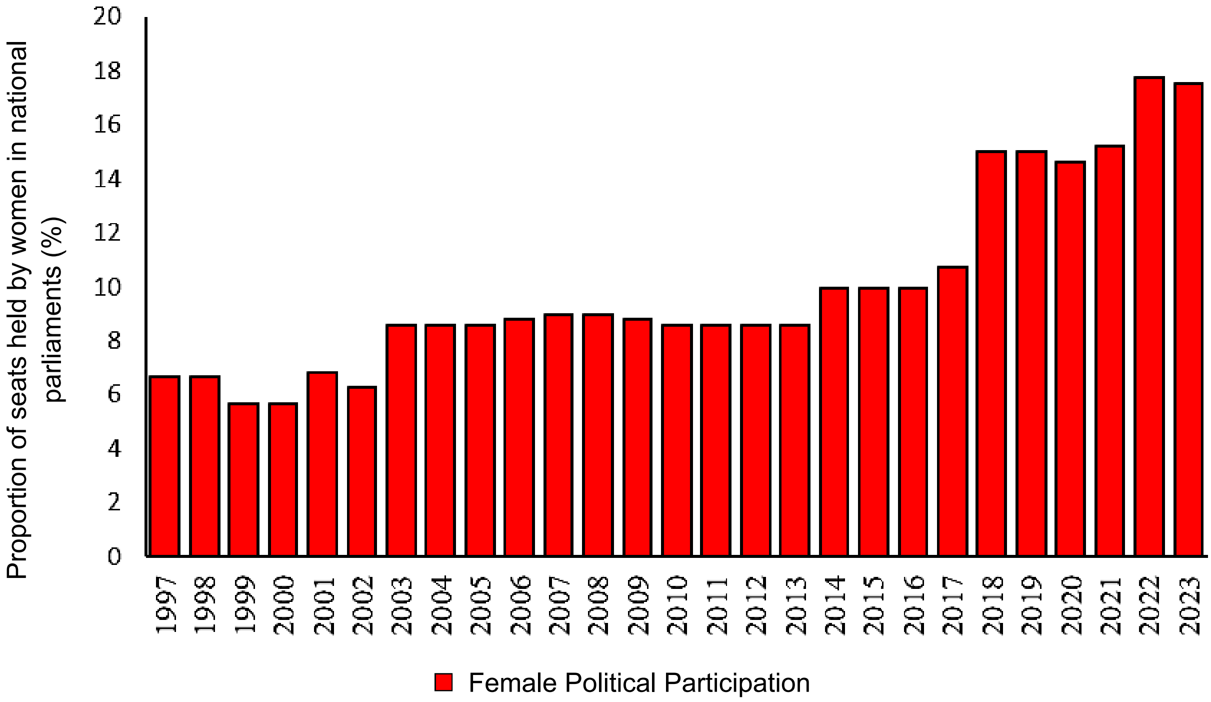
1. Introduction

An estimated one billion people, accounting for 13% of the worldwide population, lack access to electricity. Additionally, over 3 billion people, comprising 41% of the globe's population, rely on traditional energy sources, including charcoal, kerosene and firewood for lighting and cooking (WB, 2018). As a result, prominent global organizations emphasize that access to contemporary energy services is crucial for reducing poverty (WB, 2018), a complex undertaking hindered by the necessity to decrease GHG emissions to mitigate the effects of climate change. This idea is reflected in former UN Secretary-General Ban Ki-Moon's view, which described energy as "the golden thread that links economic growth, social equity and environmental sustainability" (UN, 2018). This viewpoint has played a role in creating Sustainable Development Goal 7 (SDG7), which seeks to guarantee that all people have access to cheap and dependable energy by the year 2030. In this vein, worldwide initiatives to combat energy poverty primarily focus on technical aspects, aiming to enhance the availability of contemporary energy sources and attain low consumption rates. These initiatives are aimed at improving the welfare of impoverished populations.

Humans use energy to produce goods and services, which is crucial to boosting the global economy. In Brazil, energy consumption has grown significantly, with a significant growth of 92% from 701 kg per capita in 1971 to 1,490 kg in 2014 (WDI, 2024a). This increase in energy consumption has translated into economic growth, with GDP per capita increasing from USD 3,866 in 1971 to USD 9,023 in 2023 (WDI, 2024d). Nevertheless, despite the economic achievement, a substantial segment of Brazil's population continues to encounter difficulties obtaining dependable and affordable energy. This scenario exemplifies a long-standing disparity between Brazil's growth and equitable energy access. In Brazil, 47.8% of the households face energy deprivation, indicating that a substantial portion of the population struggles to meet their energy-related needs. This deprivation is particularly evident in access to thermal comfort services, with 20.1% of households lacking this basic service (Marcoje *et al.*, 2017). Additionally, 35.3% of the households lack proper laundry facilities and 22.9% do not have access to water heating (Marcoje *et al.*, 2017). These gaps in energy access have significant consequences for quality of life and contribute to broader issues of poverty. Therefore, it is essential to tackle this inequality in order to promote equitable economic development and enhance the general standard of living in Brazil.

Recent literature has examined how female political participation affects energy poverty (*e.g.*, Acheampong *et al.*, 2024; Ngarava *et al.*, 2022; Nguyen and Su, 2021). The studies have found that increased representation of women in political roles correlates with more inclusive and equitable policy outcomes, including energy access and poverty reduction (Nguyen and Su, 2021; Sen *et al.*, 2023). Women in leadership positions often advocate for policies that directly address the needs of underserved populations, including energy accessibility for the poor (Anser *et al.*, 2024). Brazil has seen some progress in increasing female representation in politics (see Figure 1); however, it remains below the global average, suggesting that more needs to be done to leverage the potential impact of female political participation on reducing energy poverty (WDI, 2024c). Financial globalization is another critical factor that can affect energy poverty, although research into this relationship has been limited. This relationship can be both positive and negative. Necessary capital for infrastructure development can also be provided by financial resources (Wang *et al*., 2024). This can aid in limiting energy poverty, thus improving access to dependable and affordable services. On the flip side, energy poverty can also be increased by financial globalization (Hassan *et al*., 2022; Khan *et al*., 2023). This can be done if the benefits of financial flows are not distributed equally or if it leads to a surge in energy prices due to speculative investments and market volatility. Moreover, the emphasis on short-term financial profits by international investors might weaken long-term investments in green energy infrastructure, which can result in energy poverty. Therefore, while financial globalization provides potential avenues for addressing energy poverty, it also brings about obstacles that must be effectively addressed to provide equitable and enduring access to energy.

Figure 1: Trend of female political participation in Brazil



Source: WDI (2024c)

The effect of economic policy uncertainty on energy poverty has also been given limited attention in the literature. It can influence energy poverty through an uncertain environment, dissuading investment in the energy sector. An increase in economic policy uncertainty makes it difficult for investors to commit their resources to energy infrastructure projects (Che and Jiang, 2021; Zhang *et al*., 2023). This uncertainty can influence energy accessibility through delays in critical energy infrastructure. In addition, the costs of curtailing uncertainty in economic policy can increase energy prices (Ogede *et al*., 2023). This can affect low-income households and, as a result, intensify energy poverty. Therefore, it can be said that energy poverty can be reduced through a predictable and stable policy environment, which is crucial in providing enduring and equitable energy accessibility. Based on the above background, the study raises the following research questions:

- How does female political participation affect energy poverty in Brazil?
- What role does financial globalization play in shaping energy poverty in Brazil?
- How do financial development and economic policy uncertainty influence energy poverty in Brazil?

The study contributes to the existing literature regarding access to energy in the following ways. Firstly, this is the inaugural study investigating how female political participation and financial globalization affect energy poverty. Secondly, unlike prior research (*e.g.*, Acheampong *et al*., 2024; Ngarava *et al*., 2022; Nguyen and Su, 2021), the present study considers different periods (short, medium and long term) and quantiles in investigating this connection, which will help in proposing practical policy recommendations. Thirdly, this study makes a methodological contribution by introducing the wavelet Zivot–Andrews (WZA), an advancement over the conventional Zivot and Andrews (1992) unit root test. The WZA test offers a significant advantage over the traditional Zivot–Andrews unit root test by enhancing its ability to detect a single structural break in time series data across different frequencies or scales.

This rest of paper is organized as follows: Section 2 reviews the literature, Section 3 presents the data and methodology, Section 4 details empirical findings and discussion, and Section 5 concludes the study.

2. Literature Review

Female political participation is vital for shaping energy policies and combating energy poverty. Research indicates that higher female representation in political decision-making can lead to more inclusive and equitable energy policies. Acheampong *et al*. (2024) used data from 2000 to 2021 to investigate the drivers of energy poverty. The authors used 98 countries and the 2GMM technique, and their results showed that a surge in electrification fosters a surge in the gender parity index in secondary and tertiary education. Besides, female literacy and communication adversely affect energy poverty. In another study with a focus on curbing emissions, Anser *et al*. (2024) used the proportion of seats held by women in national parliaments (%) as a proxy for female political participation in examining the drivers of energy poverty using data from 1990 to 2020. The study used Malaysia as a case, and the findings showed that female political participation surges emissions and does not lead to the goal of carbon neutrality.

Using data between 2008 and 2014, Crentsil *et al*. (2019) inspected the determinants of multidimensional energy poverty in Ghana. The results showed significant interrelationships between households' multidimensional energy poverty status and household characteristics. Ogwumike and Ozughalu (2016) analysed Nigeria's energy poverty drivers with data from the National Bureau of Statistics. The outcomes showed that the gender and age of the household head and region of residence affect energy poverty. The authors suggested that it is imperative to make concerted efforts to address the issue of energy poverty in Nigeria effectively. Similarly, Sy and Mokaddem (2022) looked at the determinants of energy poverty using primary data obtained from 1,000 households in Mumbai. Their findings showed an insignificant association between the education level of households and energy poverty. In addition, education and awareness of energy issues mitigate energy poverty.

Similarly, Gafa and Egbendewe (2021) used primary data for Senegal and Togo in examining energy poverty in rural West Africa. Their findings indicate that the degrees of energy poverty in rural areas range from 31.2% to 98.5% in Senegal and from 53.5 to 98.8% in Togo. With the motif of proposing policies to reduce energy poverty, Awan *et al*. (2022) analysed energy poverty trend drivers in Pakistan using data from 1998 to 2019. The authors employed two energy poverty measures to analyse this connection. The results of their probit model disclosed that households with less education, female-headed families and low endowments are more likely to be energy-poor. Using India as a case, Jahanger *et al*. (2024) employed quantile-based estimators to explain how financial development and economic growth interact with energy poverty. The study used quarterly data from 1990 to 2020, concluding that financial development and economic growth are major drivers of the surge in energy poverty in India, while the effect of human capital is weak.

In another investigation, Khan *et al*. (2023) used the CS-ARDL estimator to examine the association between financial inclusion and energy poverty using the global economy as a case. The authors found that a decrease in energy poverty is credited to a surge in financial inclusion and globalization. Using 27 European countries, Zhao *et al*. (2022) inspected how globalization and bureaucracy influence energy poverty, and the outcomes showed that globalization and bureaucracy significantly affect energy poverty. In a similar investigation by Hassan *et al*. (2022), the authors reported that a reduction in emissions and energy poverty is attributed to an increase in globalization. Moreover, Che and Jiang (2021) reported a significant association between economic policy uncertainty and energy poverty. Using sub-Saharan Africa for an analysis, the investigation by Ogede *et al*. (2023) using CS-ARDL and PQR techniques showed that a spike in energy poverty is credited to the upsurge in economic policy uncertainty. Ogede *et al*. (2023) investigated the impact of economic policy uncertainty on energy poverty. In another investigation, Nguyen *et al*. (2021) reported that financial development can alleviate energy poverty. The study of Dong *et al*. (2022) also affirmed the perspective of Nguyen *et al*. (2021) by disclosing the energy poverty increase in financial development decreases energy poverty.

Based on the above review, there is a clear gap in the literature. Firstly, though prior studies have significantly explored the drivers of energy poverty, no study has been dedicated to the role of financial globalization and female political participation. We fill this gap by examining the effect of financial globalization and female political participation on energy poverty. Secondly, the majority of the studies in the domain of access to energy have neglected the policy directions across various periods (short, medium and long term). We fill this gap by considering this association across various periods and quantiles, which will help propose effective policies. Thirdly, though the majority of these studies consider stationarity attributes of the variables before the main analysis, these studies do not consider the stationarity attributes across various time scales. We fill this gap by using a wavelet-based Zivot and Andrews unit root test to capture the stationarity and break data across different time scales.

3. Data and Methods

3.1 Data

This section provides information about the selected variables. Energy poverty is the dependent variable, while the regressors are financial development, financial globalization, economic policy uncertainty and female political participation. The study covers the period from 1997 to 2022. All the data are annual. To ensure conformity to normal distribution and reduce heteroscedasticity, we applied the natural logarithm to all the data. Additionally, due to limited data availability, we transformed annual data into quarterly data. Therefore, the study utilizes data spanning from Q1 1997 to Q4 2022. Further information is shown in Table 1.

Table 2 displays the data statistical information. The mean values indicate that ln *EPU* has the highest average, followed by ln *EP*, ln *FD*, ln *FG* and ln *FP*. The medians are close to the means, suggesting relatively symmetric distributions, especially for ln *EPU* and ln *FG*. However, the skewness values reveal that ln *EP* and ln *FG* are negatively skewed, meaning that they have longer tails on the left side, while ln *EPU* and ln *FP* are positively skewed. The standard deviations show that ln *EPU* has the highest variability while ln *FG* has the lowest. The kurtosis values indicate that ln *FD* has a flatter distribution than a normal distribution, while ln *FG* peaks more. The Jarque–Bera test suggests that ln *EP*, ln *FD* and ln *FG* significantly deviate from normality (indicated by their low *p*-values), while ln *EPU* and ln *FP* do not show significant departures from normality at the conventional level.

Table 1: Measurement, sources and variables

Symbol	Variable	Measurement	Source
EP	Energy poverty	Energy poverty composite index	Author´s calculation
FD	Financial development	Domestic credit to private sector by banks (% of GDP)	WDI (2024)
FP	Female political participation	Proportion of seats held by women in national parliaments (%)	WDI (2024c)
EPU	Economic policy uncertainty	Index	PU (2024)
FG	Financial globalization	Index	KOF (2024)

Source: Author's own elaboration

Table 2: Descriptive statistics

	ln *EP*	**ln *EPU***	**ln *FD***	**ln *FG***	**ln *FP***
Mean	4.4977	4.8951	3.8338	3.8353	2.2200
Median	4.5338	4.8828	3.9088	3.8375	2.1687
Maximum	4.5976	6.1308	4.2718	4.0078	2.9504
Minimum	4.2562	3.9310	3.3161	3.4804	1.6993
Std. dev.	0.1010	0.4795	0.3437	0.1168	0.3055
Skewness	−0.8345	0.2193	−0.2680	−0.7284	0.4855
Kurtosis	2.4247	2.6919	1.3975	3.1650	2.6606
JB	13.505***	1.2455	12.372***	9.3149***	4.5847
Probability	0.0011	0.5364	0.0020	0.0094	0.1010

Note: *** denotes statistical significance at the 1% levels.
Source: Author's own calculations

3.2 Empirical methods

The study employs a series of techniques to examine the drivers of energy poverty. Below is detailed information on the stages of the techniques used.

3.2.1 Wavelet Zivot–Andrews unit root test

The traditional Zivot and Andrews (ZA) test suggested by Zivot and Andrews (1992) is usually specified as follows (considering a break in both the intercept and trend):

$$\Delta Y_t = \alpha + \delta t + \sum_{i=1}^{\kappa} \beta \Delta Y_{t-i} + \gamma D_t + u_t \tag{1}$$

where $\Delta Y_t = Y_t - Y_{t-1}$ represents the first difference of the time series. Also, α and δt depict constant (intercept) and linear time trends; γD_t depicts a dummy variable for the structural break. In addition, u_t and κ denote the error term and number of lags, respectively.
Though the Zivot and Andrews (ZA) effectively captures the stationarity of variables at a specific break date, it does not consider different time scales. Thus, the study extends the wavelet to the Zivot and Andrews (1992) test.

Granger (1966) noted that time series exhibit peak power at low-frequency components, which diminishes exponentially as frequency increases. Recent studies, including those by Fan and Gençay (2010) and Aydin and Pata (2020), have explored wavelet-based unit root tests in this context. We employ maximal overlap discrete wavelet transform (MODWT) suggested by Percival and Walden (2000) following the studies of Ozkan *et al*. (2024) and Adebayo and Özkan (2024) to decompose Y_t. MODWT achieves better time-frequency localization compared to DWT. It uses overlapping wavelet transforms, which can provide a more detailed representation of signals, especially in capturing transient features and sudden changes in the signal (Percival and Walden, 2000). In addition, MODWT is better suited for analyzing non-stationary signals compared to DWT.

Let $\tilde{Y}_t$ represent the wavelet-transformed series. The wavelet Zivot–Andrews (WZA) at a certain decomposition level is depicted as follows:

$$\Delta \tilde{Y}_t^{(i)} = \alpha^{(i)} + \delta t^{(i)} + \sum_{j=1}^{\kappa} \beta^{(i)} \Delta \tilde{Y}_{t-j}^{(i)} + \gamma D_t^{(i)} + u_t^{(i)} \tag{2}$$

where $\tilde{Y}_t^{(i)}$ depicts the wavelet-transformed series at the scale i. The first difference of the wavelet-transformed series at the scale i is illustrated by $\Delta \tilde{Y}_t^{(i)}$. The structural break dummy for the scale i is denoted by $D_t^{(i)} \times \alpha_i$ and $\delta t^{(i)}$ represent the intercept term for the series i and the deterministic trend term. In addition, $u_t^{(i)}$ represents the error term.

The null and alternative hypotheses are:

H_0: At a given wavelet scale, the time series contains a unit root with no structural break.

H_1: At a given wavelet scale, the time series is stationary with one structural break.

3.2.2 Wavelet quantile-on-quantile regression

We employ the wavelet quantile-on-quantile regression (WQQR) introduced by Ozkan *et al.* (2024). This method simplifies the impact of the independent variable on the independent variable, focusing on different quantiles and periods of both dependent and independent variables. The conventional quantile-on-quantile regression (QQR) suggested by Sim and Zhou (2015) is specified as follows:

$$\underbrace{Y_t = \beta_0(\delta, \phi) + \beta_1(\delta, \phi)\left(X_{i,t} - X_i^{\phi}\right) + e_t^{\delta}}_{*} \tag{3}$$

where Y_t depicts the dependent variable at the time t. $\beta_0(\delta, \varphi)$ stands for intercept, which is a function of the parameters δ and φ. Furthermore, $\beta_1(\delta, \varphi)$ represents the slope or coefficient of the independent variable.The error term is denoted by e_t^{δ}.

Over the years, several studies (*e.g.*, AlNemer *et al.*, 2023; Bilgili *et al.*, 2021; Kumar and Padakandla, 2022; Magazzino *et al.*, 2022), have identified that the relationship between variables changes across various time scales. However, the QQR cannot detect the impact of X quantiles on Y quantiles across various time scales. This implies that it is crucial to consider various time scales regarding the effect of independent variable quantiles on dependent variable quantiles. The variables are decomposed by using the MODWT introduced by Percival and Walden (2000). The WQQR at a certain decomposition level J is depicted as follows:

$$\underbrace{d_j\left[Y_t\right] = \beta_0(\delta, \varphi) + \beta_1(\delta, \varphi)\left(d_j\left[X_{i,t}\right] - d_j\left[X_i^{\varphi}\right]\right) + e_t^{\delta}}_{*} \tag{4}$$

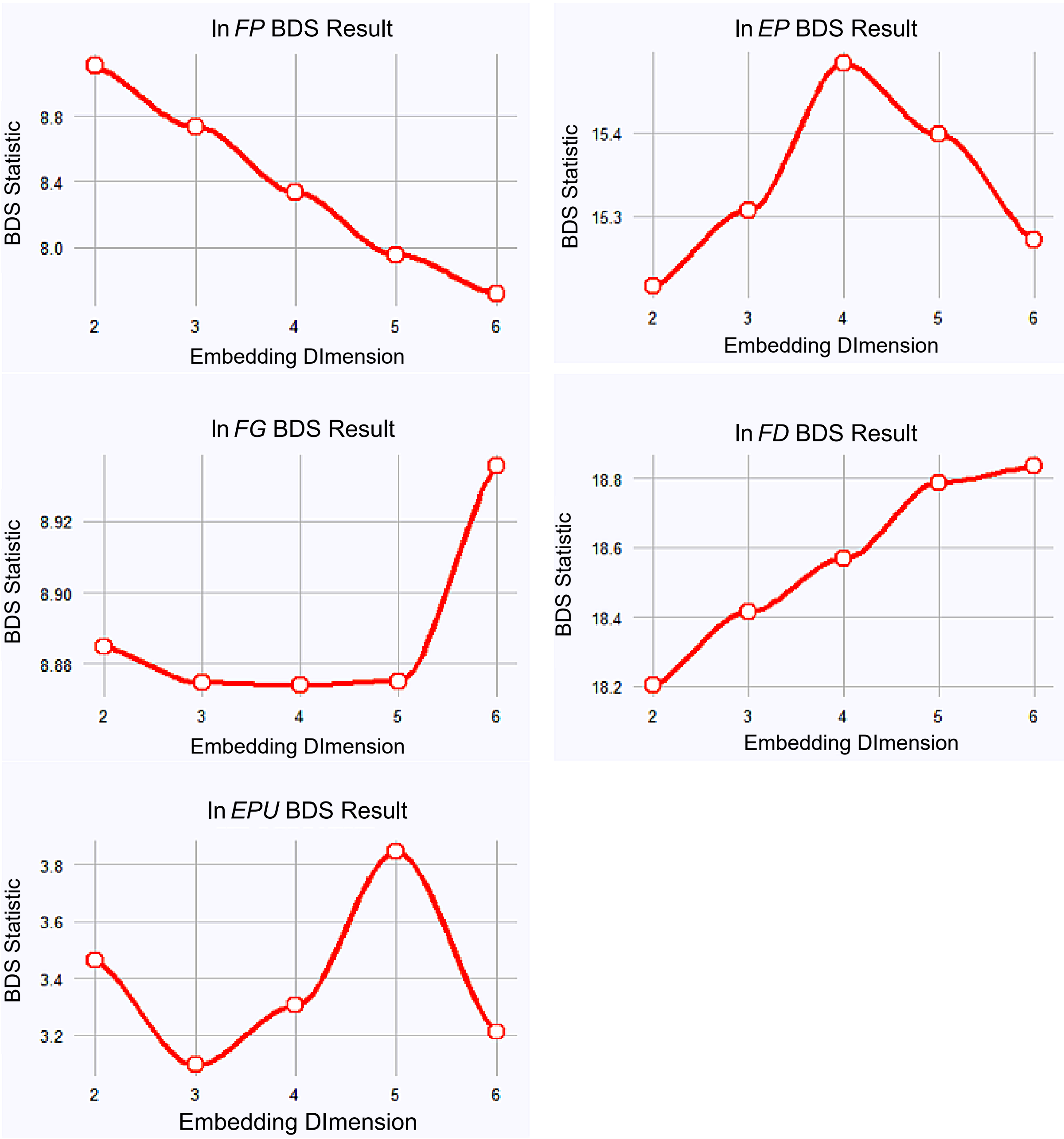
where the coefficients β_0 and β_1 depend on the parameters δ and φ, indicating that these factors influence the relationship between variables. The model captures dynamics at different frequencies and allows for varying error behaviour through e_t^{δ}.

4. Findings and Discussion

4.1 Nonlinearity test results

We begin the main estimation by examining the nonlinear attributes of the series. The BDS test, proposed by Broock *et al.* (1996), is employed to evaluate the nonlinear characteristics of ln *EP*, ln *EPU*, ln *FG*, ln *FP* and ln *FD*. Figure 2 presents the findings of the BDS test. The null hypothesis of "linearity" is rejected at the 1% significance level for each dimension (M2–M6) for all the variables. The results of various statistical tests, including skewness, kurtosis, Jarque–Bera and BDS, confirm the non-normal distribution and nonlinear attributes of the variables. Consequently, we apply nonlinear approaches for the analysis.

Figure 2: Nonlinearity test outcomes



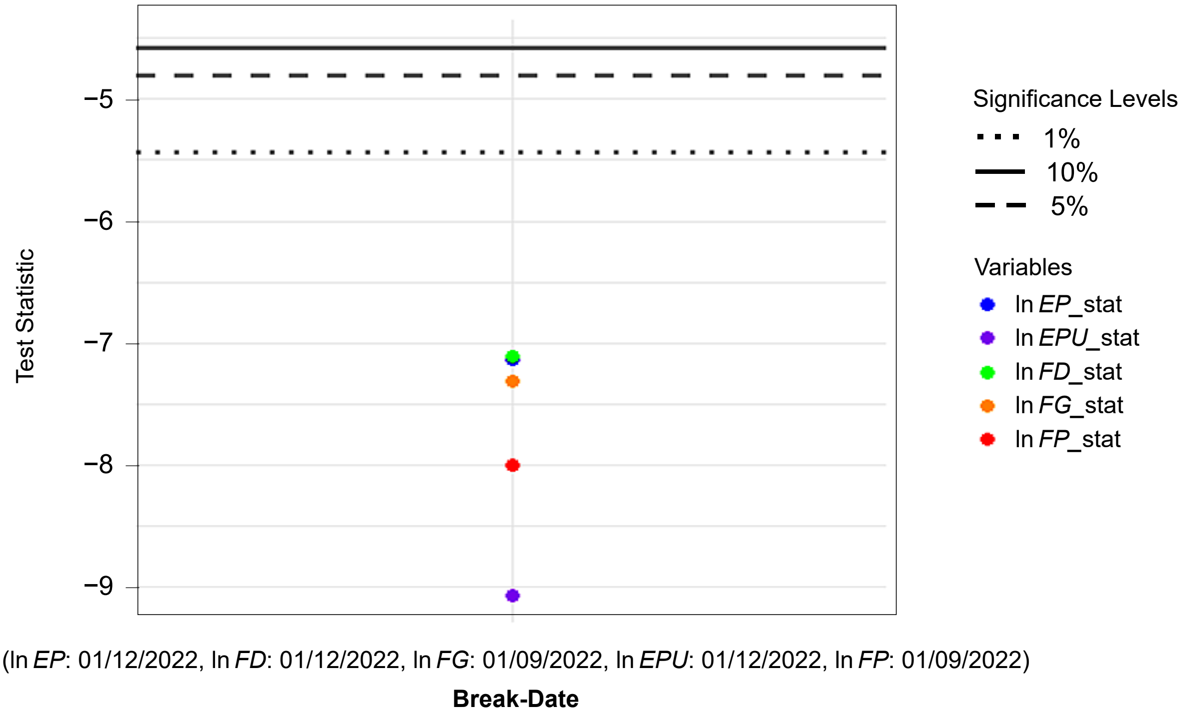
Note: Horizontal and vertical axes show the embedding dimension and BDS statistics.
Source: Author's own elaboration

4.2 Stationarity test results

We use the wavelet Zivot–Andrews (WZA) unit root test to identify the stationarity attribute of the series at a specific break date and time scale. The results of the WZA are shown in Figure 3 (a, b and c).

Figure 3a shows the results of the WZA in the short term. In the short run, the WZA test results show that for ln *EP*, ln *EPU*, ln *FG*, ln *FP* and ln *FD*, the null hypothesis is rejected at the wavelet scale, indicating that these series are stationary after accounting for a structural break. Specifically, the test statistics for all the variables fall below the critical value thresholds (1%, 5% and 10%), meaning that they do not exhibit a unit root at the analysed frequency level and are thus stable in the short run.

Figure 3a: Short term

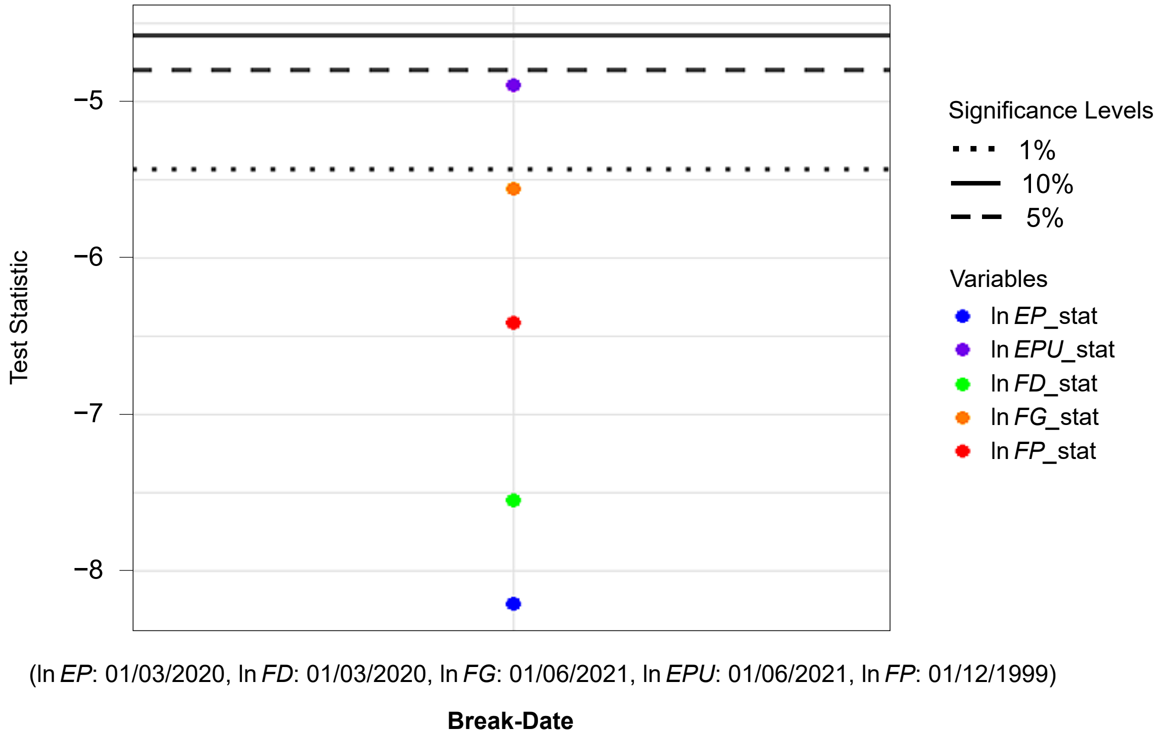


Notes: Dotted, dashed and solid lines denote the significance levels of 1% and 5%, respectively. Optimal lag lengths (p) were selected automatically using the AIC. The 1%, 5% and 10% critical values of the *T*-statistics are −5.57, −5.08 and −4.82, respectively.

Source: Author's own elaboration

Figure 3b shows the WZA in the medium term. The results show that all the variables have test statistics that fall below the 1% critical value line. This means that for each of these variables, the null hypothesis is refuted at the 10% significance level. The dismissal of the null hypothesis indicates that these series are stationary after accounting for a structural break.

Figure 3b: Medium term

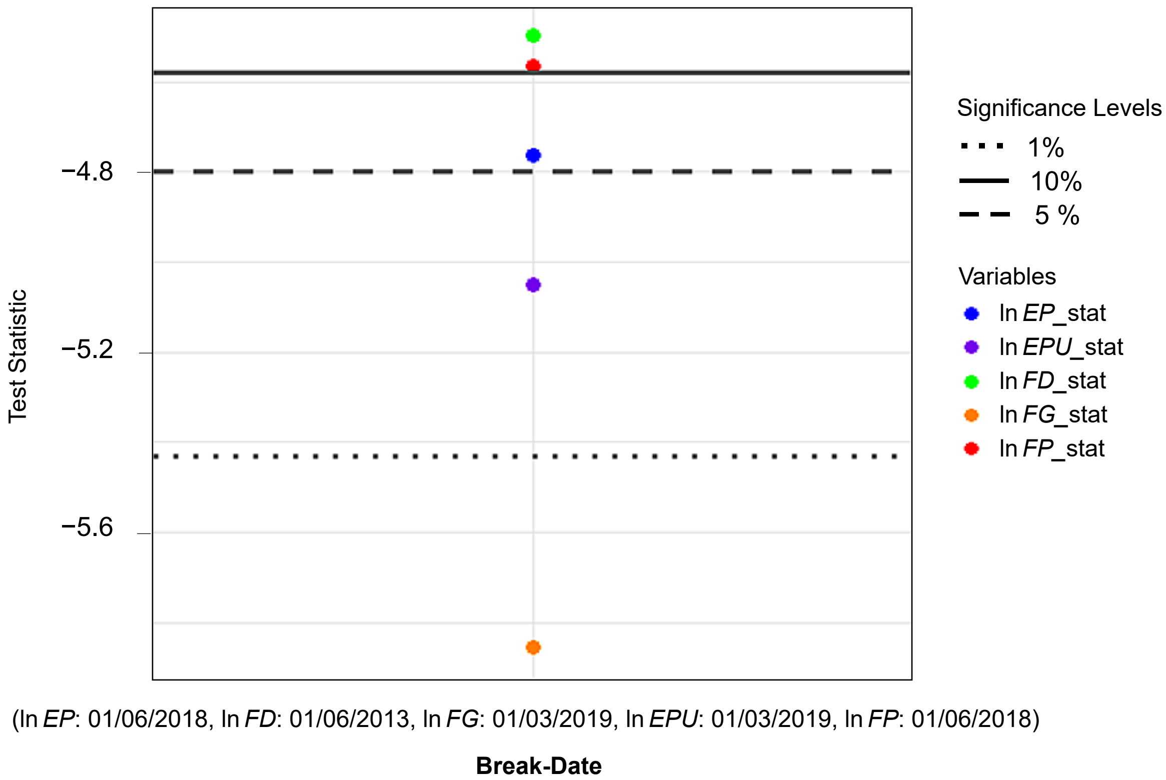


Notes: Dotted, dashed and solid lines denote the significance levels of 1% and 5%, respectively. Optimal lag lengths (p) were selected automatically using the AIC. The 1%, 5% and 10% critical values of the *T*-statistics are −5.57, −5.08 and −4.82, respectively.

Source: Author's own elaboration

In the long term (see Figure 3c), the test statistics for ln *EP* (blue), ln *EPU* (purple) and ln *FG* (orange) fall below the 10% significance level line. This indicates that the null hypothesis for these variables is dismissed at the 10% significance level, implying that these series are stationary after accounting for a structural break. On the other hand, the test statistics for ln *FD* and ln *FP* fall above the 10% significance level line. This means that the null hypothesis for ln *FD* (green) and ln *FP* (red) is not rejected at the 10% significance level, indicating that these series are non-stationary and may contain a unit root.

Figure 3c: Long term



Notes: Dotted, dashed and solid lines denote the significance levels of 1% and 5%, respectively. Optimal lag lengths (p) were selected automatically using the AIC. The 1%, 5% and 10% critical values of the *T*-statistics are −5.57, −5.08 and −4.82, respectively.

Source: Author's own elaboration

4.3 Wavelet quantile-on-quantile regressions

We use the WQQR to examine the effect of the ln *EPU*, ln *FG*, ln *FP* and ln *FD* on ln *EP* (see Figures 4, 5, 6 and 7). The left-hand side figure shows the WQQR, while the right-hand side figure shows their corresponding *p*-value.

Figure 4 shows the effect of ln *FP* on ln *EP*. In the short term (see Figure 4a), the increase in energy poverty due to female political participation, despite being weak, could be attributed to the initial stages of integrating female perspectives into political processes, where immediate impacts on energy poverty are not yet fully realized and the challenges of addressing entrenched energy access issues may still dominate (Hassan *et al.*, 2022; Khan *et al.*, 2023). In the medium term (see Figure 4b), the decrease in energy poverty in the lower quantiles of energy poverty as female political participation increases suggests that as women gain more political power, they begin to effectively advocate for policies that target and reduce energy poverty among the most vulnerable groups. However, the continued increase in energy poverty in the middle and upper quantiles could indicate that these policies are not yet broad-based or fully effective across all societal segments, possibly due to resistance or the time required to gain widespread impact (Khan *et al.*, 2023). In the long term (see Figure 4c), despite being weak, the persistent increase in energy poverty in the middle and upper quantiles might reflect the ongoing challenges in translating political participation into tangible energy access improvements for all, with benefits being more concentrated in specific groups. However, the decrease in energy poverty in the lower quantiles suggests that female political participation contributes to lessening energy poverty among the most disadvantaged over time, even if the overall impact remains modest.

Figure 4: Impact of ln FP on ln EP

Figure 4a: Short term

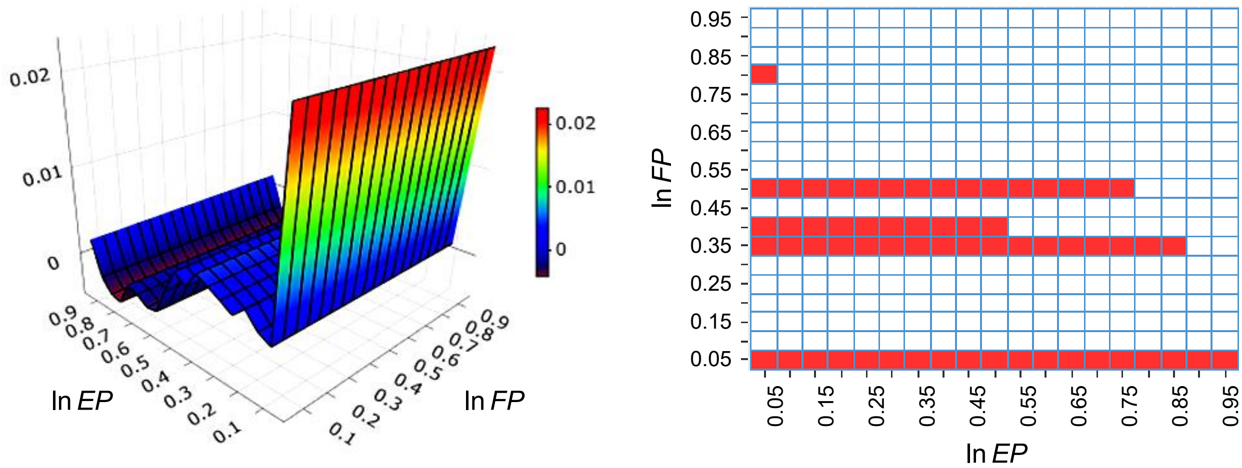


Figure 4b: Medium term

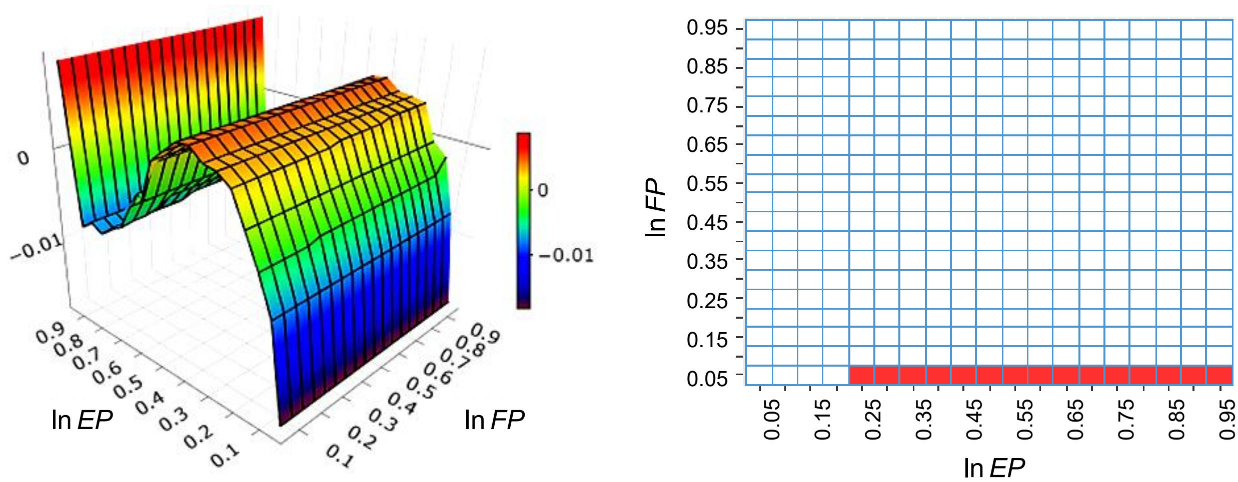
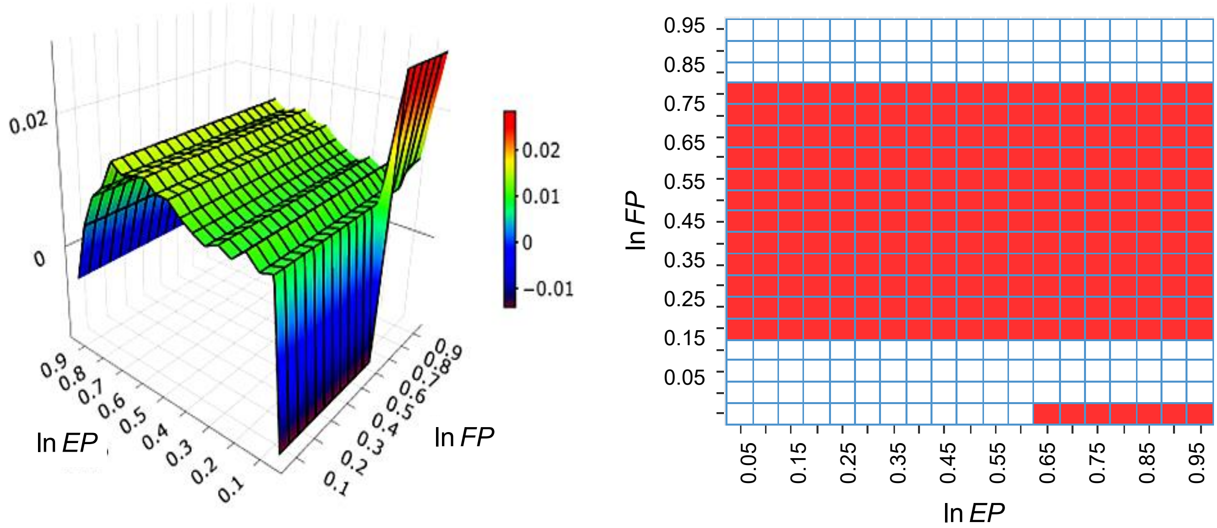


Figure 4c: Long term



Source: Author's own elaboration

Figure 5 shows the effect of financial globalization (*FG*) on energy poverty (*EP*) in Brazil. In the short term (see Figure 5a), the observed increase in energy poverty associated with rising financial globalization, albeit insignificant, may suggest that the initial influx of global financial flows and investments does not immediately translate into improvements in energy access for the broader population. This could be due to the focus of financial globalization on sectors that do not directly benefit the energy needs of the poorer segments or the lag in policy adjustments to harness these financial flows effectively. In the medium term (see Figure 5b), the continued increase in energy poverty, even as financial globalization deepens, indicates that while the global financial integration is starting to have a more pronounced effect, its benefits are not equitably distributed, leading to a widening gap in energy access, particularly in the lower and upper quantiles of the population. The weak but significant relationship may reflect structural barriers that prevent the poor from benefiting from financial globalization, such as regulatory challenges or inadequate infrastructure. In the long term (see Figure 5c), the significant and pervasive impact of financial globalization on energy poverty across all quantiles suggests that as Brazil becomes more integrated into the global financial system, the influence of these global financial forces becomes more entrenched, affecting energy poverty across the board.

Figure 5: Impact of ln *FP* on ln *EP*

Figure 5a: Short term

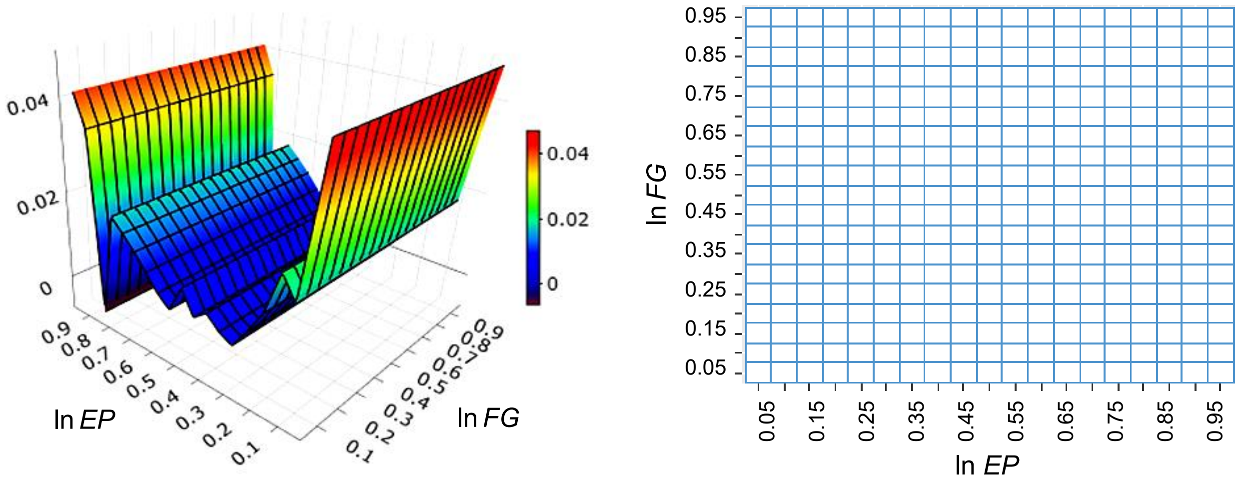


Figure 5b: Medium term

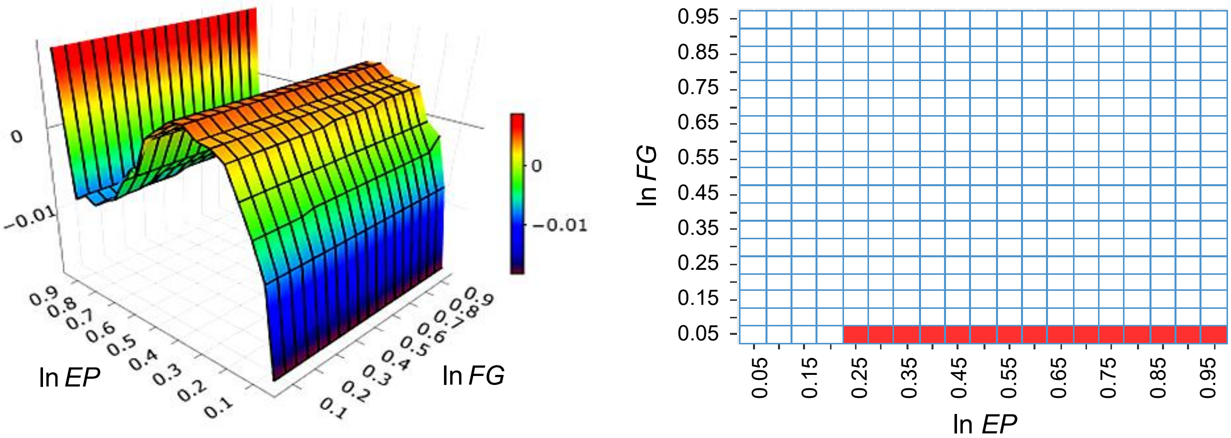
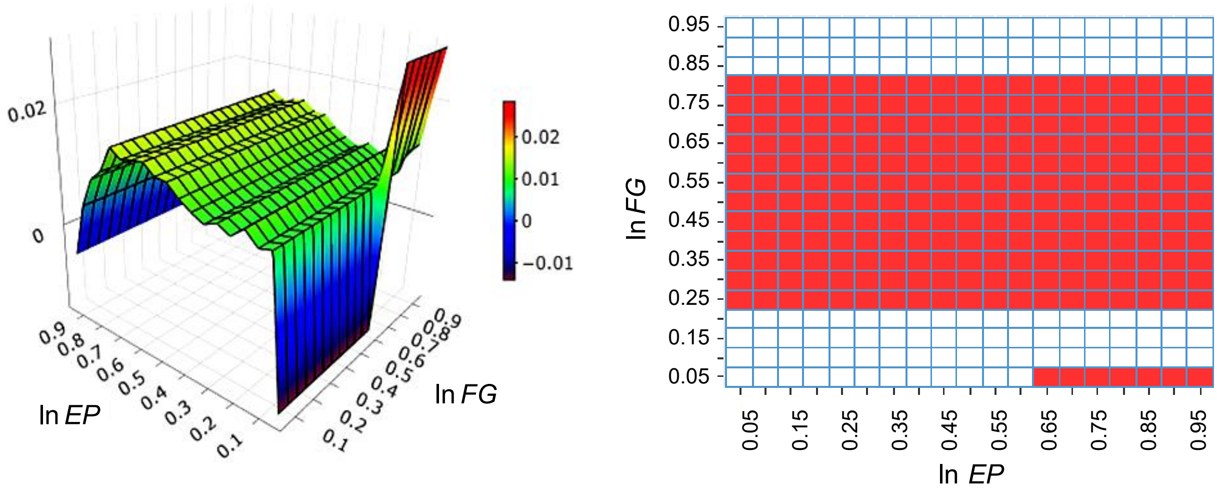


Figure 5c: Long term



Source: Authors' own elaboration

Figure 6 shows the effect of energy policy uncertainty (*EPU*) on energy poverty (*EP*) in Brazil. In the short term (see Figure 6a), the observed decrease in energy poverty despite rising energy policy uncertainty might suggest that initial fluctuations or uncertainties in policy may trigger temporary adjustments or compensatory measures that mitigate the immediate impact on energy access (Che and Jiang, 2021). This could be due to short-term interventions or the resilience of existing energy systems that buffer against policy shifts, albeit with weak significance. However, in the medium term (see Figure 6b), the increase in both *EPU* and *EP* across all quantiles suggests that sustained uncertainty begins to erode these initial buffers, leading to a deterioration in energy access. The weak significance of this relationship may reflect the gradual and uneven effects of prolonged policy instability, where certain populations start to feel the impact more acutely than others (Ogede *et al*., 2023). In the long term (see Figure 6c), the continued positive relationship between *EPU* and *EP*, albeit with weak significance, indicates that prolonged policy uncertainty has a compounding effect on energy poverty, as persistent instability in energy policies likely undermines investments and the development of sustainable energy infrastructure (Zhang *et al*., 2023).

Figure 7 shows the effect of financial development (*FD*) on energy poverty (*EP*). In the short term (see Figure 7a), the increase in financial development leads to a decrease in energy poverty across all quantiles, with significant p-values, suggesting that early stages of financial development effectively enhance energy access for the population. This likely reflects improved availability of financial resources and credit, which can facilitate investments in energy infrastructure and make energy services more accessible to the broader population (Dong *et al*., 2022). In the medium term (see Figure 7b), this positive relationship continues, indicating that as the financial sector matures, its benefits of reducing energy poverty remain strong and pervasive. However, in the long term (see Figure 7c), in the extreme low quantiles, an increase in financial development leads to higher energy poverty, possibly due to financial services being less accessible or more costly for the poorest segments, exacerbating their vulnerability (Jahanger *et al*., 2024; Nguyen *et al*., 2021). On the other hand, in the middle and upper quantiles, financial development continues to reduce energy poverty significantly, likely because these groups are better positioned to utilize financial services to improve energy access.

Figure 6: Impact of ln EPU on ln EP

Figure 6a: Short term

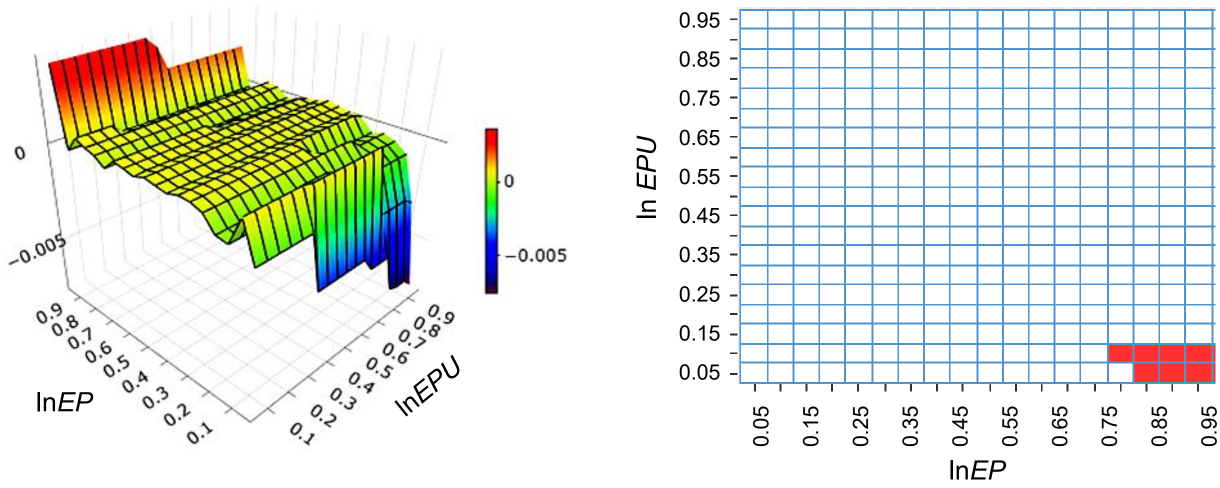


Figure 6b: Medium term

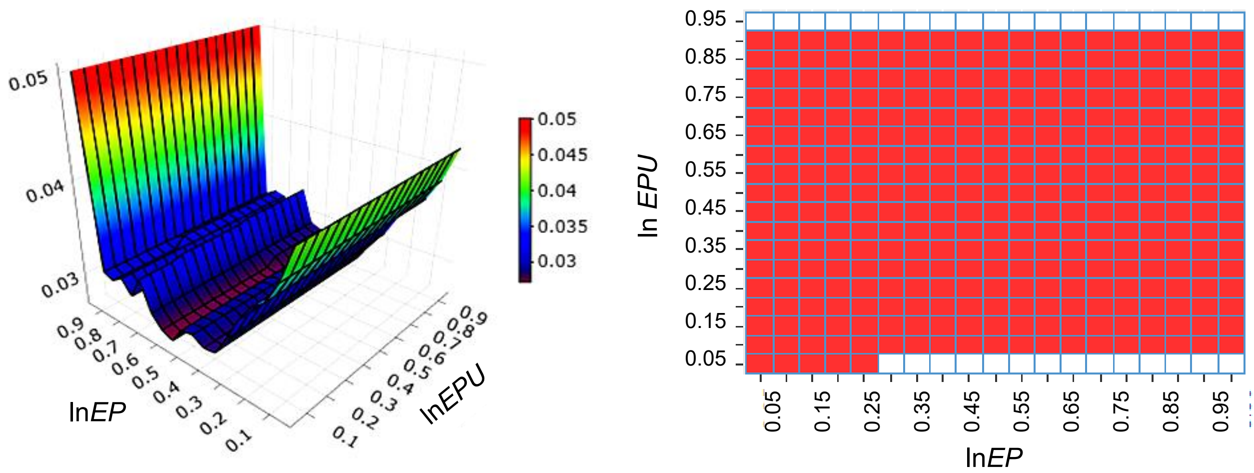
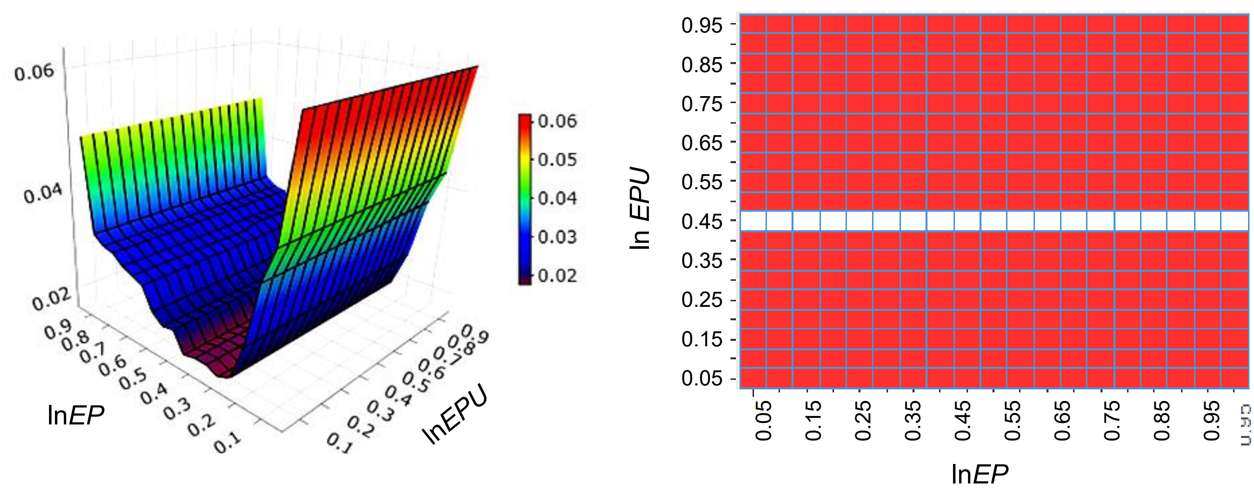


Figure 6c: Long term



Source: Authors' own elaboration

Figure 7:

Figure 7a: Short term

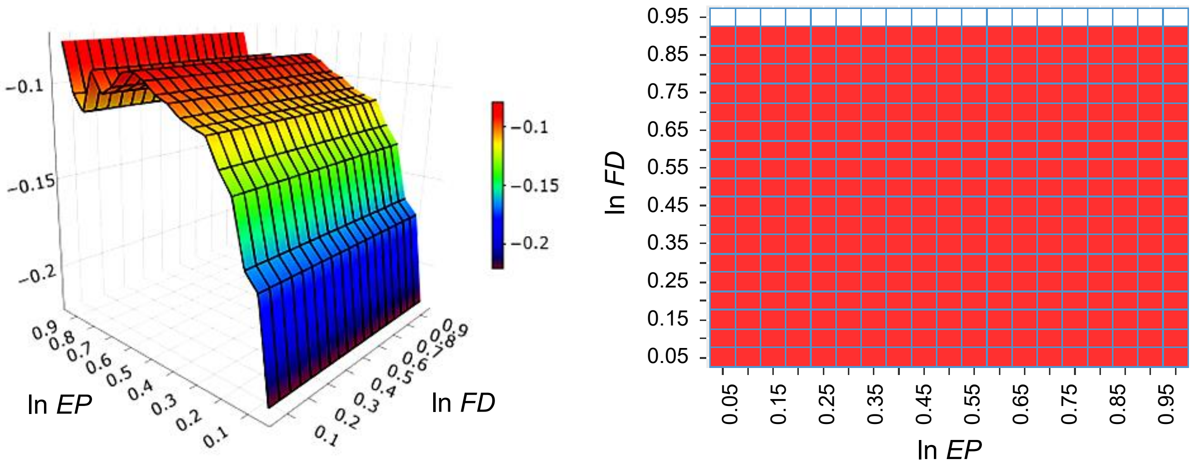


Figure 7b: Medium term

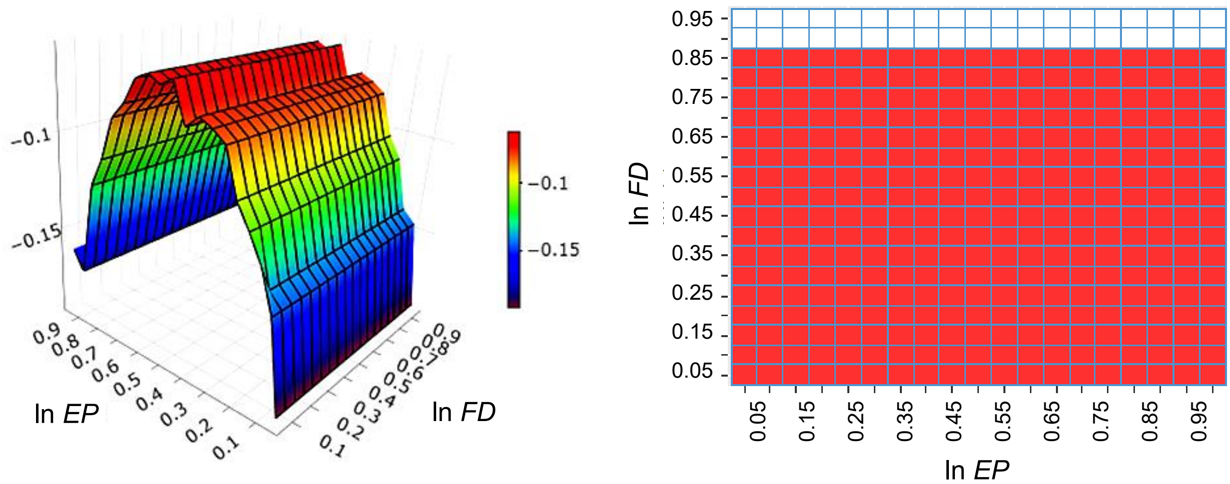
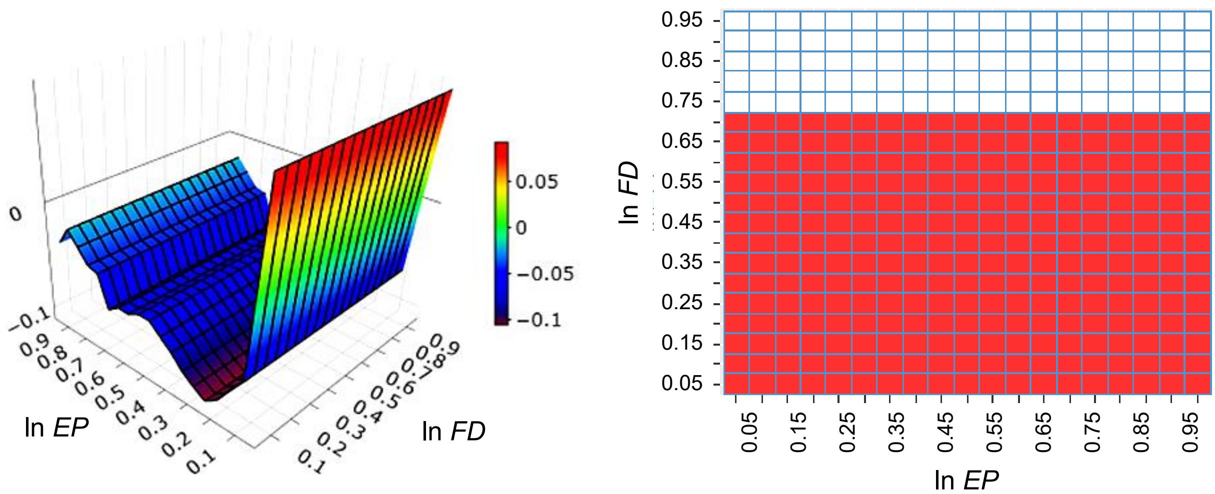


Figure 7c: Long term



4.4 Robustness check

As a robustness check, we compare the average WQQR and WQR coefficients. The results are shown in Figures 8, 9, 10 and 11.

In Figure 8, the results show that across all quantiles and periods, an increase in female political participation is accompanied by a surge in energy poverty in the short (see Figure 8a) and long term (see Figure 8c); however, in the medium term (see Figure 8b) and in the upper and lower quantiles, an increase in female political participation decreases energy poverty.

Figure 8: Comparison between AWQQR and WQR regarding the impact of *FP* on *EP*

Figure 8a: Short term

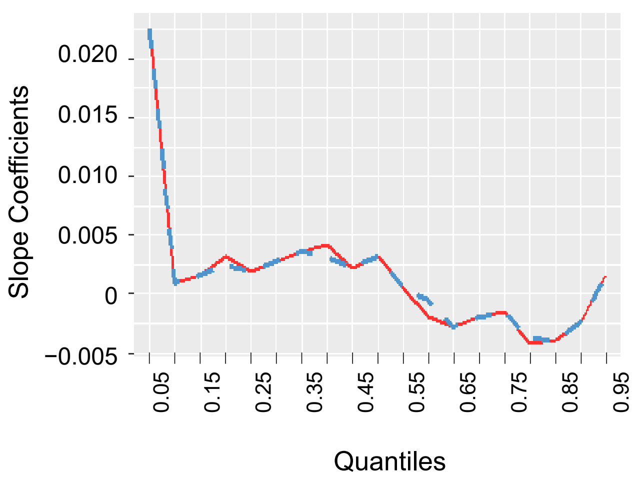


Figure 8b: Medium term

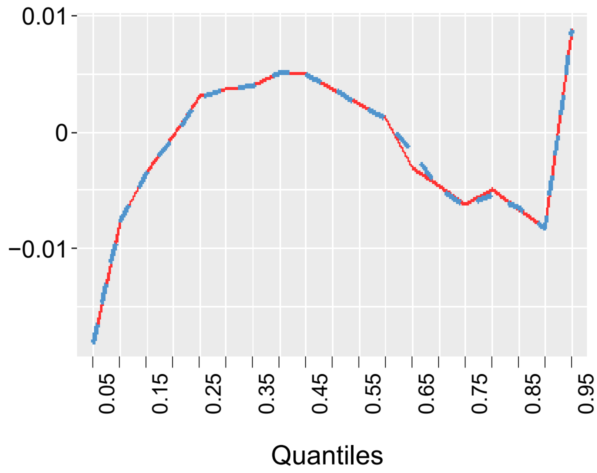


Figure 8c: Long term

Source: Author's own elaboration

Figure 9 compares the AWQQR and WQR coefficients regarding the effect of economic policy uncertainty on energy poverty. The results show that an increase in economic policy uncertainty increases energy poverty across all quantiles and periods (see Figures 9a, b and c). Figure 10 shows the association between financial globalization and energy poverty by comparing the coefficients of AWQQR and WQR. The results show that a surge in financial globalization causes an increase in energy poverty (see Figures 10a, b and c). Lastly, Figure 11 shows the effect of ln *FD* on ln *EP* by comparing the AWQQR and WQR coefficients. The results show that a surge in ln *FD* leads to a decrease in ln *EP* across all quantiles (see Figures 11a, b and c).

Figure 9: Comparison between AWQQR and WQR regarding the impact of ln *EPU* on ln *EP*

Figure 9a: Short term

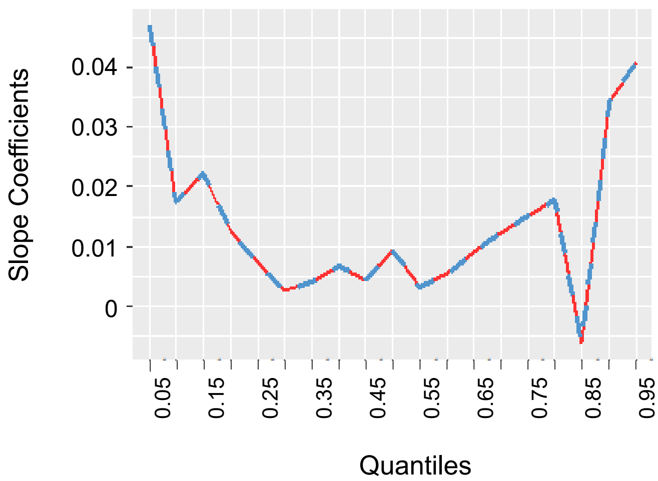


Figure 9b: Medium term

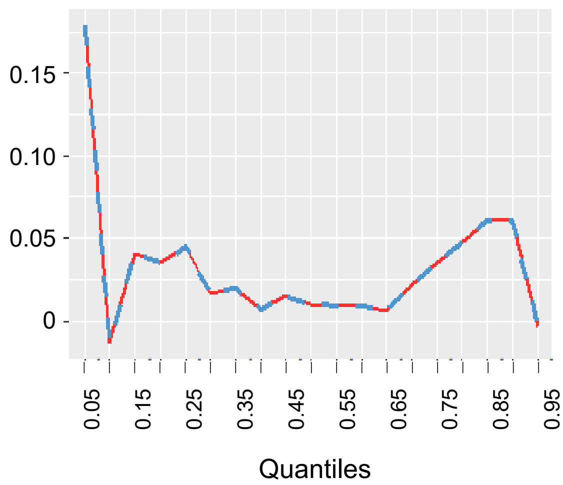
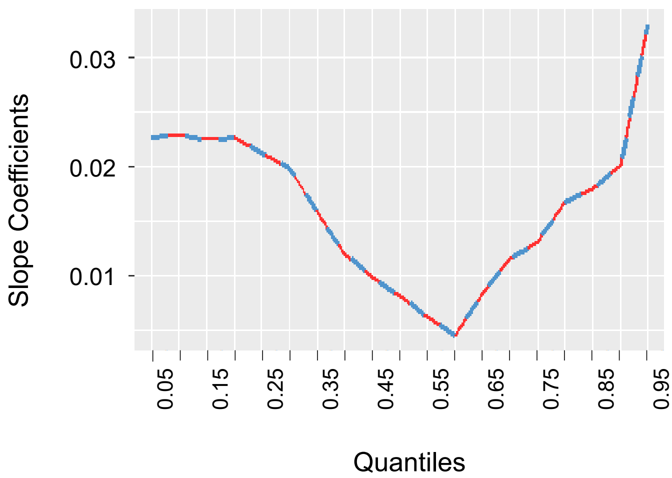


Figure 9c: Long term



Source: Author's own elaboration

Figure 10: Comparison between AWQQR and WQR regarding the impact of ln *FG* on ln *EP*

Figure 10a: Short term

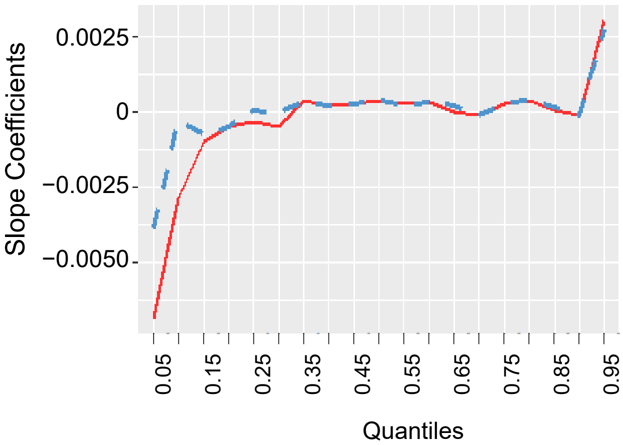
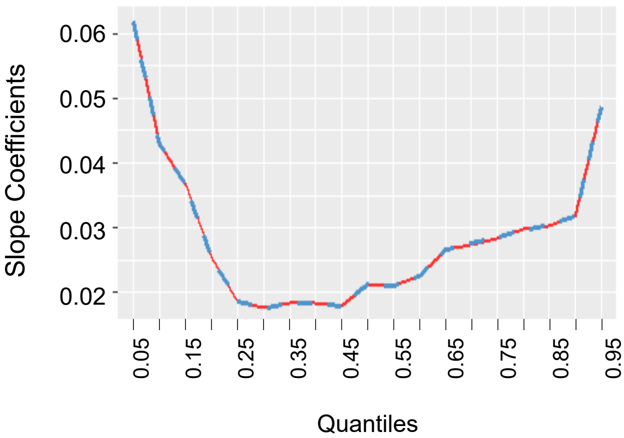


Figure 10b: Medium term

Figure 10c: Long term



Source: Author's own elaboration

Figure 11: Comparison between AWQQR and WQR regarding the impact of ln *FD* on ln *EP*

Figure 11a: Short term

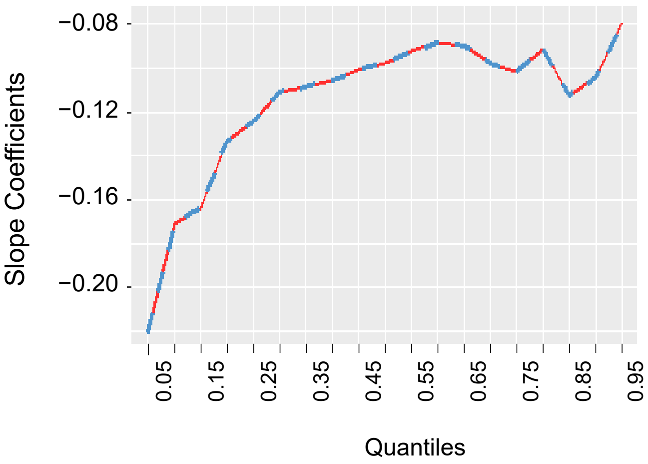
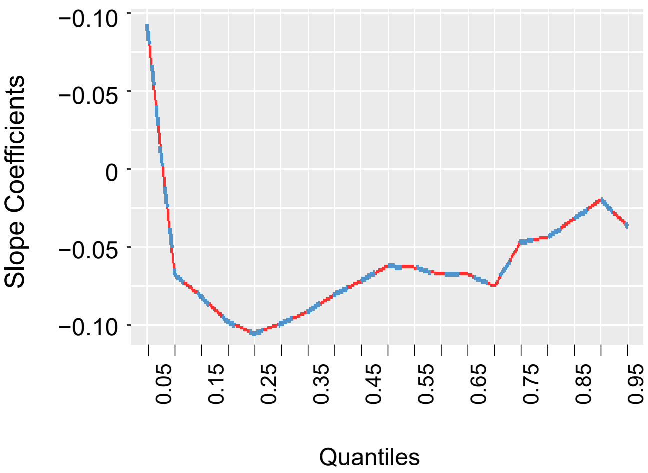


Figure 11b: Medium term

Figure 11c: Long term



Source: Author's own elaboration

5. Conclusion and Policy Remarks

5.1 Conclusion

In this study, we examined for the first time how female political participation and financial globalization affect energy poverty in Brazil. The role of economic policy uncertainty and financial development were also considered using data from 1997Q1 to 2022Q4. The study employed a series of wavelet techniques. Firstly, we introduced the wavelet Zivot–Andrews (WZA) unit root test, an extension of the conventional Zivot–Andrews (ZA) unit root test. Secondly, we employed wavelet quantile-on-quantile regression (WQQR) to identify the association between the concerned variables. The results show that across all quantiles and periods, an increase in financial globalization and economic policy uncertainty increases energy poverty. The study also shows that female political participation increases energy poverty in the short and long term while in the medium term and across all quantiles, female political participation decreases energy poverty. Lastly, an increase in financial development decreases energy poverty across all quantiles and periods.

5.2 Policy remarks

Based on these findings, policy interventions in Brazil should aim to mitigate the adverse effects of financial globalization and economic policy uncertainty on energy poverty while leveraging the positive impacts of financial development and female political participation. Given that increased financial globalization and economic policy uncertainty consistently lead to higher energy poverty across all quantiles and periods, policymakers should prioritize stabilizing economic policies and creating robust safety nets to protect vulnerable populations. This could involve implementing regulatory frameworks that ensure equitable distribution of the benefits of financial globalization, particularly by directing global financial flows towards sustainable energy infrastructure projects that directly benefit low-income households. Additionally, reducing economic policy uncertainty through transparent, consistent and forward-looking energy policies can help minimize disruptions in energy access, thereby curbing energy poverty.

Furthermore, the impact of female political participation on energy poverty suggests that policies should aim to enhance the effectiveness of women's roles in political decision-making, particularly in energy-related sectors. In the short and long term, where female political participation has been shown to increase energy poverty, efforts should be made to ensure that female political leaders are empowered with the resources and knowledge necessary to implement policies that effectively reduce energy poverty. This could include targeted training programmes, greater inclusion of women in energy policy design and ensuring that gender perspectives are integrated into all stages of policy formulation and implementation. In the medium term, where female political participation is associated with a decrease in energy poverty, these positive trends should be reinforced through policies that support and expand women's participation in political and economic decision-making, ensuring that their influence translates into tangible improvements in energy access for all. Lastly, the consistent finding that financial development reduces energy poverty highlights the need for policies that further promote financial inclusion and access to credit, particularly for underserved populations, to ensure that the benefits of financial sector growth continue to alleviate energy poverty across the board.

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