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Price and Income Elasticity of Residential Electricity Demand in the State of Bahia: 2004 to 2021

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ABSTRACT

The main objective of this research is to estimate the price and income parameters of the residential electric power demand of Bahia state, Brazil. For this, monthly data from 2004 to 2021 is used. The consumption is analyzed in terms of the electricity price, income, number of residentials, rainfall, average temperature, and residential index price. Regarding climatic variables, despite being important for the study of the electricity sector, especially rainfall, since Brazil depends on water sources, they are rarely used. After verifying that part of the series is non-stationary, it is decided to use the method of Cointegration and Error Correction Mechanism (ECM). This estimator considers the model variables and their lags, reconciling short-run and long-run trends. The results are consistent with the established hypotheses, proving to be inelastic both in the short and long run. The parameters calculated can serve as another source of information, both for the agents responsible for conducting energy planning in the State of Bahia, and for eventual investors in the private sector.

Keywords: Electricity, Electric Demand in the Residential Sector, Bahia, Cointegration
JEL Classifications: C1, C5, R1 and R2.

1. INTRODUCTION

Residential Electricity demand is based on the demand for diversified services, such as water heating, cooking and storage, room cooling, and entertainment. These needs meet by electrical appliances. Residential sector participates with 27.6% of consumption of Brazil, being the second largest sectorial consumer, behind only the industrial sector, which has a participation of 36.6% (EPE, 2021).

In Brazil, the main source of electricity is hydropower, responsible for 65.2% (EPE, 2021). Especially in State of Bahia, according to the National Electric Energy Agency (ANEEL, 2022), the main source of electricity supply is wind energy, which accounts for 40.5% of the matrix in the state. Bahia has 747 projects operating, with approximately 14,705 MW of supervised power. Of these, 5,961 MW corresponds to electricity by wind energy projects.

Studies on the estimation of elasticity parameters for the electricity sector have already been dealt with in the literature, including the Brazilian literature, which has been researching the subject since the 1980's. Modiano (1984), estimated demand for Brazil, for the three main classes of consumption: industrial, residential, and commercial. For the residential sector, the study concluded that the short run price elasticity was −0.118 and the long-run was −0.403. For income elasticity, the parameters were 0.332 (short-run) and 1.13 (long-run).

Another traditional study of Brazilian literature, which specifically researched the residential sector, was developed by Andrade and

Lobão (Andrade and Lobão, 1997). Using annual data from 1963 to 1995, the authors concluded that the short-run and long-run for price elasticity were −0.06 and −0.051, while the parameters for income were 0.121 and 0.213.

The main qualitative differences between the empirical results of the studies reside in the long run values of price elasticity and income elasticity (Feehan, 2018; Pielow et al., 2012). In the first case, it is noticed that the long-run price elasticity is smaller than the short-run one, in line with the fact that over the periods, the values of the price elasticity tend to be higher, given the implementation of new technologies, which tend to increase the range of options for individuals in relation to electricity consumption.

In addition to the research mentioned above, Table 1 illustrates seven more studies that investigated residential electricity consumption in the country. The table also highlights the period analyzes, the level of data aggregation and the econometric modeling.

In general, when analyzing the main results for the Brazilian reality, it can be inferred that the short-run price elasticities (in absolute values) are concentrated in the range between 0.2 and 0.6, and present values are lower than the long-run values while the long-run values vary between 0.1 and 1.04. The same is true for income elasticity. Its short-run values are smaller than the long-run ones, concentrated in the range of 0.04 to 1.001 and 0.54 to 1.63, respectively.

It should be noted that there are practically no research in the literature directed to individual regional analyses at the level of states in Brazil. Therefore, the present work seeks to reduce this gap. Also, it intends to answer to what extent changes in electricity price and consumer's income affect electricity consumption in the State of Bahia.

Specifically, it is intended to estimate the parameters of price elasticity, income elasticity of electricity demand, and in the short and long run of the state residential sector. In addition, is verified how other variables, like homes served, level of rainfall, and average temperature impacts electricity consumption. The analysis proposed in this research covered the period from 2004 to 2021, contributing to updating and providing new parameters for energy analysis and planning for Bahia State.

In addition to this introduction and a brief bibliographic review, this article also has a second section where the econometric strategy and sources of the data used are demonstrated. The third section describes and analyzes the main results of this study. Finally, the last section shows the conclusions and recommendations for future research.

2. METHODOLOGY AND DATA

2.1. The Econometric Model

The model estimated price elasticity, income elasticity, and other determinants of residential electricity demand in the Bahia State from 2004 to 2021. The dependent variable is residential electricity consumption measured in MWh. Six dependent variables are included: electricity price (in R$ per MWh), average *per capita* income (in R$), average rainfall (in mm), average temperature (°C), number of homes served in each period, and the Broad Consumer Price Index (IPCA), related to household items. In addition to the regressors, the model is controlled by the annual time trend, which is, 18-time control *dummy* variables are established, one for each year of the historical series analyses.

For the correct specification of the electricity demand function, it is necessary to consider that the entire amount of electricity demanded is effectively supplied, and that, theoretically, there are no losses in the system[1]. In other words, there can be no stationary demand. As electricity is in general a non-storable good, with an infinitely elastic supply, the quantity consumed can be considered a good approximation to the quantity demanded.

Combining the explanatory factors, the demand for electricity in the Bahia State can be modeled as a function of price, income, rainfall level, average temperature, inhabited residences, and residential items. In this way, the econometric strategy is used to estimate the electric energy demand of the residential sector in the State of Bahia. Followed the model of the type *ln-ln*, according to Equation 1:

$$lnc_t = \alpha + \beta_1 lnp_t + \beta_2 lnr_t + \beta_3 lnpluv_t + \beta_4 lntemp_t + \beta_5 lnres_t + \beta_5 lnipca_t + \varepsilon_t \quad (1)$$

where t represents the periods (months. from January 2004 to December 2021), lnc_t is the logarithm of residential electricity

1 According to ANEEL (2019), the average loss in transmissions and distribution is concentrated around 7.5%. However, since they vary from state to state inside Brazil and ANEEL allows concessionaries to reflect some of these losses in the price of the service, the value of the losses was not considered at the discretion of the researchers.

Table 1: Main Brazilian empirical studies on price elasticity and income of residential demand

Authors	Period	Aggregation	Methods	Short-run		Long-run	
				Price	Income	Price	Income
(Schmidt and Lima, 2004)	1969-1999	Country (annual)	VAR/VEC	-	-	−0.09	0.54
(IRFFI et al., 2009)	1970-2003	Northeast region (annual)	DOLS	−0.21	0.01	0.69	0.68
(Villareal and Moreira, 2016)	1985-2013	Country (annual)	OLS	-	-	0.23	0.19
(Dantas et al., 2016)	2000-2015	Regions (annual)	GMM	−0.152-−0.275	0.042-0.368	-	-
(Silva et al., 2018)	1991-2014	States (annual)	GMM	-	-	−0.175	1.46
(Uhr et al., 2019)	2004-2014	States (annual)	GMM	0.13-0.18	0.08-0.12	0.62-1.47	0.32-1.09
(Martins et al., 2021)	2004-2019	Country/region (monthly)	GMM	−0.103-−0.642	0.191[a] 1.001	−0.391[a] 1.043	0.288[a] 1.627

Source: Adapted from Martins et al. (2021)

consumption, α is the intercept of the demand function, lnp_t is the natural logarithm of price, lnr_t represents the income and $lnpluv_t$. $lntemp_t$. $lnres_t$ and $lnipca_t$ are the representations of rainfall level, average temperature, homes served and, IPCA of residential items in the State in each period of time. ε_t represents the model random error.

2.2. Data

The model variables, along with their definitions and origins, in addition to the results of the unit root tests, are represented in Table 2. The data are monthly and cover the period from January 2004 to December 2021, totaling 216 observations. The tests used to verify the presence of unit roots are the Augmented Dickey-Fuller (ADF) and the Phillips-Perron test (PP).

The number of regressions lags for the ADF test are determined by Akaike criterion[2]. The P-values for all variables, except rainfall, temperature and IPCA were higher than 0.05, according to the ADF and PP tests, indicating that the time series (except for *pluv*, *temp* and *ipca*) are suspected of having unit roots. However, performing the same tests with the series in difference, none of them showed evidence of unit root property. Besides, it is tested whether the residuals of the difference regressions are cointegrated. The test statistic was −12.515, outside the region of rejection of the null hypothesis, considering that the variables in difference are stationary and cointegrated.

Figure 1 shows the time series plotted from 2004 to 2021. The plots that are at the top level (*ln c*, *ln p,* and *ln r*) have similar patterns to each other. Figure 1 also reveals that these series suffered linear trends over the analyzed period. The correlation coefficient between them was above 75% (consumption and price) and above 96% (consumption and income).

Hence, after carrying out the tests and verifying the viability of the estimator, the residential electricity demand in the Bahia State is estimated using the Cointegration and Error Correction Mechanism (ECM) method. The main advantage of ECM is that it allows

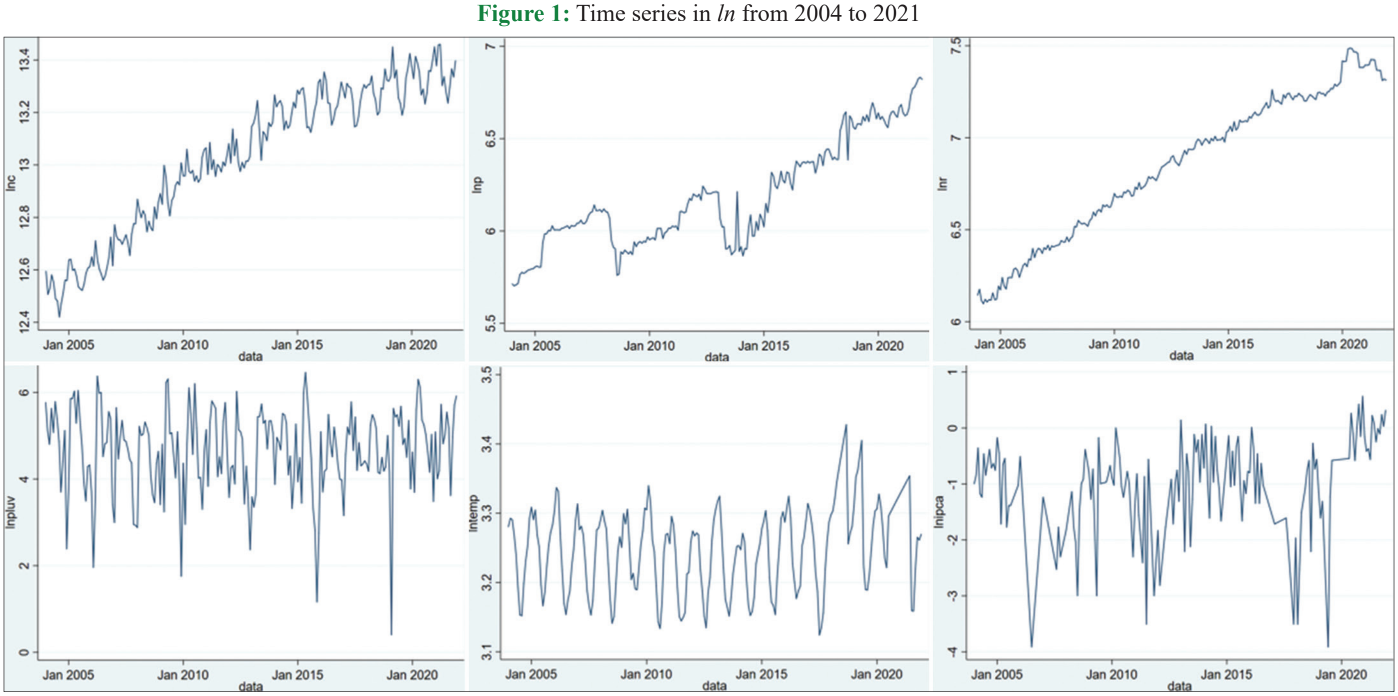
2 The AIC information criterion is a metric that measures the quality of a statistical model, also aiming at its simplicity. It therefore provides a metric for comparing and selecting models, in which lower AIC values represent greater model quality and simplicity.

Table 2: Identification of variables data sources and *P* values for unit root tests

Variables	Definition	Sources	Root unit test	
			ADF	PP
ln c	Electricity consumption-in MWh	(ANEEL, 2022)	0.464	0.571
ln p	Electricity price-in R$/MWh	(ANEEL, 2022)	0.715	0.978
ln r	Monthly *per capita* income-in R$	Continuous National Household Sample Survey (Continuous PAND) from the Brazilian Institute of Geography and Statistics (IBGE, 2021)	0.567	0.837
ln pluv	Level of rainfall-in millimeters (mm)	National Institute of Meteorology (INMET, 2021)	0.000	0.000
ln temp	Average temperature-in °C	National Institute of Meteorology (INMET, 2021)	0.000	0.000
ln res	Number of served residences	(ANEEL, 2022)	0.215	0.186
ln ipca	IPCA related to residential appliances	(IBGE, 2022)	0.000	0.000

Source: ANEEL (2022). IBGE (2021. 2022). INMET (2021). The null hypothesis for these tests is that there is a unit root. All *P* values of the ADF and PP tests for the first differences are<0.05. Indicating that these (first differences) do not have a unit root. Price and rental values are constant as of December 2020

Figure 1: Time series in *ln* from 2004 to 2021



working with variables in level, not losing the long-run relationship between them, allowing the correction of possible short-run imbalances between the variables used (Wooldridge, 2012). The ECM used in the estimation is represented as Equation 2:

$$\Delta /////_t = \alpha + \beta_1 \Delta \quad _t + \beta_2 \Delta \quad _t + \beta_3 \Delta \quad _t$$
$$+ \beta_4 \Delta lntemp_t + \beta_5 \Delta lnres_t + \beta_5 \Delta lnipca_t + \delta\varepsilon_{t-1} + \lambda_t \quad (2)$$

Where, Δ indicates the first difference of the regression. α is the intercept and $\beta_1, \beta_2, \beta_3, \beta_4$ and β_5 are the parameters of the short run elasticity. $\delta\varepsilon_{t-1}$ is the estimated residual of the cointegrated equation and λ_t is the error term with the usual assumptions.

3. RESULTS AND DISCUSSION

The model represented by Equation 1 (long-run model) is estimated and the results found showed multicollinearity, especially related to the variables *ln r* and *ln res*. Thus, four models are estimated: the first unrestricted (with all variables), a second model without income, a third model without the number of residences, and a fourth model without both variables. The results are shown in Table 3.

Even with multicollinearity, the unrestricted model (with all regressors) presented the highest adjusted statistics of R^2 and F test. Also, the estimates are the ones that presented minimum values of AIC, which implies a better adaptation of the model to the behavior of the data (Malbouisson and Tiryaki, 2017). Thus, the long-run estimated model for the electricity demand in the State of Bahia can be written as follows, according to Equation 3:

$$lnc_t = -1.386 - 0.108 lnp_t + 0.306 lnr_t + 0.007 lnpluv_t$$
$$+0.662 lntemp_t + 0.955 lnres_t + 0.004 lnipca_t + \varepsilon_t \quad (3)$$

The *t* statistic of the ADF test for the residual of the estimate is −12.442. The critical value for the cointegration test is given in function of number of observations (Maddala et al., 1997). The critical value calculated, according to the *Engle-Granger* cointegration test, with six integrated variables and 125 observations is −6.996. Thus, the hypothesis that there is no cointegration relationship was rejected, indicating that equation 3 is a cointegration relation between electricity in the Bahia State consumption and the regressors used.

Estimated long-run price and income coefficients suggest that when the price of electricity changes positively by 1%, residential electricity consumption in the state decreases to 0.108%. In relation to income, when it is increased by 1%, electricity consumption follows in the same direction to 0.306%.

The growth trend of electricity consumption in the state is also significant. The average annual growth in consumption is 18.8% between 2004 and 2021. Figure 2 illustrates the positive variation in consumption in the series (solid red line), highlighting the linear growth trend (dotted blue line).

According to evidenced in the methodological section, the series are possibly cointegrated. Therefore, the ECM was estimated. The results obtained are shown in Table 4.

The ECM represents the short-run relationship between the dependent variable (electricity consumption– *ln c*) and the explanatory variables used. The estimated values allow describing the short-run relationship between the parameters according to Equation 4:

$$\Delta lnc_t = \text{üüüüüüüüü} \; \Delta lnp_t + \quad \Delta lnr_t + \quad \Delta lnpluv_t$$
$$+\text{üüüüü} \Delta lntemp_t + \quad \Delta lnres_t - \quad \Delta lnipca_t - \quad \varepsilon_{t-1} + \lambda_t$$
(Eq.4)

The estimated short-run price elasticity was −0.045. That is, if in the short-run the price of electricity changes by 1%, consumption would shift in the opposite direction to 0.045%. In terms of income, if it increases by 1%, electricity consumption would increase to 0.324%. The values found, both in the long-run (Table 3 and Eq. 3),

Figure 2: Growth trend of residential electric consumption in the State of Bahia (2004 to 2021)

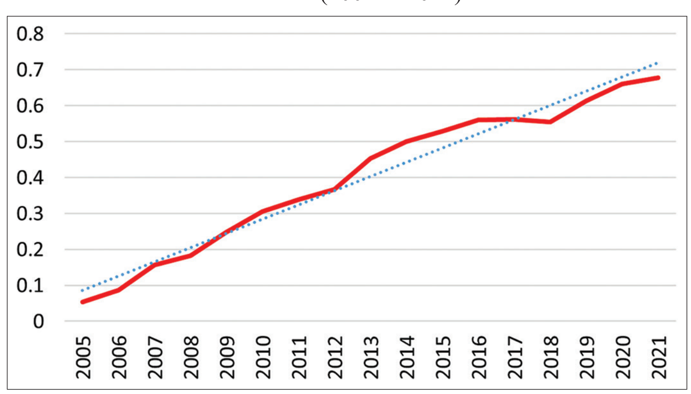


Table 3: Estimated results for long run models

Variables	Unrestricted Model	*ln r* excluded	*ln res* excluded	*ln r* and *ln res* excluded
ln p	−0.108***	−0.082	−0.074	−0.064
ln r	0.306**		−0.167	
ln pluv	0.007**	0.007*	0.004	−0.005
ln temp	0.662***	0.689***	0.604***	0.630***
ln res	0.955***	0.696***		
ln ipca	0.004	0.003	−0.003	−0.002
constant	−1.386	0.357	12.004***	10.826***
R^2	0.976	0.971	0.971	0.971
F test	230.93	215.62	230.75	221.06

Source: Research data. (***) Significant a 1%. (**) Significant at 5%, (*) Significant a 10%

Table 4: ECM estimation of residential electricity demand in the State of Bahia (2004 to 2021)

Variable	Regressor	Standard deviation	*t* Statistic
$\Delta ln\ p$	−0.045**	0.076	0.59
$\Delta ln\ r$	0.324**	0.212	−1.52
$\Delta ln\ pluv$	0.107**	0.004	3.61
$\Delta ln\ temp$	0.599***	0.144	4.14
$\Delta ln\ res$	2.694***	0.995	2.71
$\Delta ln\ ipca$	−0.005	0.006	−0.84
$\delta\varepsilon_{t-1}$	−0.270***	0.111	−2.42
Constant	0.070**	0.034	2.06

Source: Research data. (***) Significant at 1%. (**) Significant at 5%, (*) Significant at 10%

and in the short-run (Table 4 and Eq. 4), have expected signs and are consistent with economic theory.

The estimated adjustment coefficient was significant at 1%. This parameter shows the proportion of short-run unbalance in residential electricity demand in the Bahia State which is corrected from the following period. Specifically in the present study, the estimated value of 0.27 indicates that 27% of the difference between the effective value and the long-run value (equilibrium value) is corrected each period. Thus, according to the analysis, the residential sector in the state would take approximately 4 months to adjust the quantity of electricity demanded to possible shocks in price and/or income.

The *Shapiro-Wilk* test, for normality of residuals showed at 5% significance that the residuals behaved normally. The test statistic value was 0.94. The *Portmanteau* test statistic for checking whether the residues are *white noise*[3]. is 0.307, indicating that the random perturbation is a white residue.

4. CONCLUSIONS

This research contributes as another source of information for analysis and decision-making in the residential electricity sector in the Bahia State. The results were found to allow public managers, responsible for energy planning in the state, as well as electricity distributors and suppliers in general, and possibly private sector investors, to better plan the expansion of their business, in view of the increase in demand for residential electricity.

The results show that the demand for electricity in the state is inelastic to price and income, both in the short and long run. In both scenarios, the results are also significant by at least 5%. The parameter value in the short run is −0.045, while in the long run, it is −0.108. The figures illustrate that price increase policy, such as the public policy of tariff flags, and the application of fines, would not be the ideal tools to contain or inhibit electricity consumption in the Bahia State.

In relation to income, the values are also inelastic, but slightly higher (in module): 0.306 (long run) and 0.324 (short run). In both periods the values are relatively close (and significant at 5%). showing that income is a variable that affects electricity consumption in the State of Bahia residential sector more effectively.

The climatic variables, especially the average temperature, are also important in the process of analyzing the residential electricity demand in the State. The temperature is significant at 1% and presented values of 0.662 and 0.599, for the short and long-run, respectively. Taking into consideration that this state is a warmer weather region, with average temperatures around 26ºC, it is likely that the use of air conditioners is intense, contributing to a greater impact on consumption.

The rainfall index was significant with a minimum of 5%, but with greater influence in the short run (0.107). Probably, the influence of rainfall on residential consumption in Bahia State is limited, due to the greater participation of wind energy in its electrical matrix. According to ANEEL (2022). this value exceeds 40% of the state's installed capacity.

Finally, the results also showed that any external shocks, both in the price of electricity and income, can take approximately 4 months to be eliminated. This period shows a measure of rigidity in the residential structure of the Bahia State's electricity sector, also common to other regions of the country since electricity is characterized as inelastic good with no close substitutes.

3 This is a test for the presence of serial correlation. The null hypothesis for the test is that there is a serial correlation. Hence, if the p value is greater than 0.05, we reject the null hypothesis of the test.

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