Research Article

Income elasticity of electric energy consumption for different economic sectors in countries of the world

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ABSTRACT

The causal relationship between energy demand and GDP has been the subject of intense research over the past three decades. The present work seeks to analyze the energy consumption evolution of different countries worldwide and the relation of the same with the level of economic development, represented by income. For this purpose, an annual database containing gross domestic product and electricity consumption of 143 countries in the period between 1990 and 2014 was prepared. Thus, linear regression models and autoregressive vector models were used to explain the electricity consumption of countries and groups of countries. The results indicated that there is no standard elasticity behavior for most countries with similar levels of economic development. Despite this, a good performance was observed in the simple linear regression for aggregate data in groups of countries, which indicates the possibility of performing a reliable aggregate planning.

Keywords: *Electricity Demand, Energy Consumption, Income, GDP, Elasticity*

1. INTRODUCTION

Essential for the development and prosperity of mankind, energy plays an important role in the process of economic development of countries around the world. The importance of access to energy for production and therefore development is widely recognized. Lack of access to energy makes it difficult if not impossible for a country to overcome challenges such as poverty, air pollution, low levels of life expectancy, lack of access of both essential health services and to quality education, adaptation and mitigation of climate change, food production and security, economic growth and employment, sustainable industrialization and gender inequality. Thus, it is possible to relate energy consumption to the development of a country. One of the main development indicators of a country is the variation of the Gross Domestic Product (GDP), used to measure the level of economic activity. Despite not being the most appropriate indicator, since it does not consider data such as income distribution, investment in education, among others, GDP is the main economic indicator used in consumption projections and is directly related to the level of development of a country, more specifically its income. Electric power is one of the most common forms of energy used. Its discovery made great technological development

possible and its use has been essential in society. In addition to providing greater comfort to the population, its use provides an increase in the production capacity in an economy.

Many researches have been made about the relationship between energy consumption and economic growth. Among these researches, Sultan et al. (2019) highlight that researches investigate the association between energy consumption and economic growth that presents conflicting results. Sultan et al. (2019) emphasize that since the first oil price shock in 1973, many researchers have investigated the relationship between energy consumption and economic growth, finding different results. These researches generally seek to verify the causal relationship between energy demand and GDP.

The plot presented in Fig. 1 shows the association between electricity consumption and income, given by GDP. The data refers to annual per capita information on electricity consumption and GDP in 143 countries around the world, adjusted to a second-order polynomial model. From this estimation, it can be inferred that the data adjusts to a polynomial growth model. In other words, per capita electricity consumption grows more sharply than per capita GDP when the latter has lower values, representing the behavior of developing countries. However, such growth gradually decreases as per capita GDP increases, until it stagnates or even becomes negative, a behavior characteristic of developed countries where the population decreases or has no growth and energy efficiency is high. Showing a clear existence of a causal relationship between energy consumption and economic growth. In order to deepen the study of this relation, it is important to highlight the possibility that the economic sectors have different behaviors and react differently to economic changes. Figs 2, 3 and 4 show the behavior of industrial, commercial and residential consumption respectively in relation to income measured by GDP in the selected countries of the sample used. Fig. 2 was elaborated from a simple linear regression model, where per capita industrial consumption is the dependent variable and the per capita industrial GDP is the explanatory or independent variable. The coefficient of determination of the model has an explanation of 68.4%. Demonstrating a clear linear growth. That is, industrial consumption per capita increases as does the GDP per capita showing the elasticity of energy demand in relation to GDP close to 0.84. In the analysis of commercial electricity consumption per capita in relation to commercial GDP per capita, the coefficient of determination is 0.86. This means that this model is able to explain the observed values better than the per capita industrial consumption in relation to per capita industrial GDP model presented above. Moreover, it can be seen in Fig. 3 that the behavior has adjusted to a polynomial growth of second order, that is, the consumption of commercial electricity per capita shows a more accentuated growth in relation to GDP per capita, when it presents smaller values, representing the behavior of developing countries. On the other hand, such growth slows gradually as GDP per capita increases. This behavior is characteristic of developed countries. This model, therefore, behaves similarly to the per capita electricity consumption in relation to per capita GDP model presented in Fig. 3.

Finally, a simple linear regression model has estimated in which residential energy consumption per capita is the dependent variable and the per capita GDP is the explanatory variable. The coefficient of determination is 0.79, which means that the estimated model has a lower explanation than that obtained by means of the commercial

electricity consumption per capita model in relation to the industrial GDP per capita model and higher than that obtained through the industrial consumption per capita in relation to industrial GDP per capita models. It should also be noted that residential consumption per capita shows a more pronounced growth in relation to GDP per capita when the latter shows lower values, representing the behavior of developing countries. However, this growth slows as GDP per capita increases.

This is a characteristic of developed countries. It is evident, therefore, that the sectors of an economy have different behaviors and react differently to changes in the economic activities. Thus, the importance of studying the relationship between energy consumption and GDP separately from the different sectors of the economy is confirmed. This way, the present work used this methodology, separating the data in the residential, industrial and commercial sectors. The share of demand that does not fit into any of these sectors was grouped in the sector entitled "others." Moreover, this relationship between energy consumption and income may vary according to the level of development of a country, of a group of countries, that is, the income elasticity of consumption or the influence of income, or the income variation, may be different according to the economic activity level of each country.

This work aims at estimating the behavior of electric energy consumption evolution of different sectors and countries of the world and the relation of this behavior with the level of economic development, given by the income elasticity of this consumption. Given that the study is global in scope, a top-down approach was chosen, relating energy consumption to GDP. This methodology was chosen because there is data from reliable sources available from several countries around the world, which would not occur with too specific and detailed data needed for a bottom-up approach. In addition, this is a long-term view analysis and a macroeconomic approach is quite adequate and most used. The relationship between energy consumption and GDP for selected countries in the period between 1990 and 2014 was verified through two stochastic models, namely: linear regression model and autoregressive vector model. In order to make the data more easily comparable, per capita values were used throughout the study.

Fig. 1. Energy Consumption vs GDP

Fig. 2. Industrial Consumption vs GDP

Fig. 3. Commercial Consumption vs GDP

Fig. 4. Residential Consumption vs GDP

The present article is structured as follows: the next section contemplates the literature review where a selection of other studies that approached the same theme is presented. Section 3 deals with the methodological approach and data used. Section 4 presents the results obtained, along with their respective analyzes and, finally, Section 5, presents the conclusion and final comments.

2. LITERATURE REVIEW

The empirical literature provides diverse and conflicting evidence regarding the energy consumption growth and its drivers. This discrepancy in the results is mainly due to the use of different econometric methods and time periods, in addition to the specific variables of each country or region, such as climate, economic development and energy consumption patterns.

In this way, it is noteworthy that Kraft and Kraft (1978) were pioneers to investigate the relationship between energy consumption and economic growth using various econometric methods for different time periods. At first, from an economic perspective, it is understood that energy is an important production factor. However, empirical evidence suggests that the energy growth nexus is complicated. An important reference to this theme is Ozturk (2010). Additionally, other relevant previous studies are Yu and Hwang (1984), Yu and Choi (1985), Lee (2005), Apergis and Payne (2009) and Fulei (2010). From these perspectives, it is interesting to analyze different studies that present different results on this question and to understand the reasons that generate these differences.

According to Jamil and Ahmad (2011), Saatci and Dumrul (2013) and Huang (2014), economic growth drives the growth in energy demand. Huang (2014) analyzes the key factors that led to increased global energy demand in recent decades, mainly using annual data between 1980 and 2009 for a sample of 24 OECD countries. In addition to the elasticity of price and income, which are traditionally examined, this research analyzes the effects of climate, demographic, structural and technological changes on energy demand. In this perspective, using the panel data technique, this research evidenced the presence of spatial lag dependence, in addition to the existence of a positive but decreasing income elasticity and a negative price elasticity. In addition, the study analysis has shown that industrialization and urbanization increase energy use, while the development of service economies and technological innovations tend to reduce demand. The study of the

Institute of Electrical and Electronics Engineers - IEEE (2008) shows that, on average, the demand for energy does not increase in direct proportion to the increase in income but proportion to the per capita income; both at level and in composition. Generally, the more advanced the economy and the higher the per capita income, the greater the demand for energy-using equipment. It should also be mentioned that Jamil and Ahmad (2011) conclude that the demand for electricity depends essentially on income and price. Jamil and Ahmad (2011) analyze electricity demand in Pakistan between 1961 and 2008, using annual aggregate and sectoral data for residential, commercial, industrial and agricultural groups. The results indicate that electricity demand responds to real economic activity at aggregate and sectoral levels. Demand was elastic in relation to the price for all cases, except for the agricultural sector. The inelasticity of this sector is due to the highly subsidized nature of the agricultural tariff in Pakistan. The analysis also concludes that long run elasticities are consistently superior to short run elasticities. These results are interesting from the political point of view because they show that the price of electricity can be used as an efficient tool for energy conservation. On the other hand, Lee (2005) concludes that the growth of energy demand impacts economic growth. Lee (2005) investigates the co-movement and the causal relationship between energy consumption and GDP in 18 developing countries, using data spanning from 1975 to 2001. The unit root of the panel, cointegration of the heterogeneous panel and panel-based error correction models tests are used. It is evident that in the long and short term the causalities go from energy consumption to GDP, but not the other way around. This result indicates that energy conservation can undermine economic growth in developing countries, whether transitory or permanent.

Belke et al. (2010) and Magazzino (2014) show the existence of a bidirectional causal relationship between energy demand and economic growth. Belke et al. (2010) examine the long-term relationship between energy consumption and GDP, including energy prices, for 25 countries of Organization for Economic Co-operation and Development -- OECD from 1981 to 2007. The distinction between common factors and idiosyncratic components was possible using principal components analysis (PCA) procedure, which allowed distinguishing between development on an international plan and a national level as drivers of a long-term relationship. In fact, the cointegration among the common components of the underlying variables indicates that international development dominates the long run relationship between energy consumption and real GDP. Besides that, the results suggest that energy consumption is inelastic in terms of prices. The causality tests indicate the presence of a bidirectional causal relationship between energy consumption and economic growth. Magazzino (2014), on the other hand, applies time series methodologies to examine the causal relationship between electricity demand, GDP per capita and the labor force in Italy between 1970 and 2009. The results indicate that there is a relation of cointegration between these variables, with coefficients statistically significant. In addition, the study points to a bidirectional flow of Granger causality between GDP per capita and electric demand.

In recent years many researches on energy consumption have been done. Among these studies, Ajlouni (2016) seeks to determine the response in residential electricity

consumption both in the short and long terms with the price and income variables by estimating the price and the income elasticities of electricity demand in the Jordanian residential sector. With a methodological approach based on an autoregressive model with distributed lag (ARDL) and using data from the period 1980 to 2013, Ajlouni (2016) inferred that demand is more sensitive to income variation than price variation, that is, demand responds more incisively to the income variation than the price variation. Ajlouni (2016) adds the variable temperature in the model construction to explain electricity consumption in the Jordanian residential sector and points out that temperature is a determining variable for electricity demand in that sector. In a different study, Yasar (2017) examines the relationship between energy consumption and economic growth in 119 countries divided into 4 groups classified by income, from 1970 to 2015, and verify whether the causal relationship between the two variables in question differs between the two variables. Yasar (2017) presents an extensive bibliographic review and applies a methodology that includes stationarity and cointegration tests through ARDL models and autoregressive vector models with error correction, for comparative cointegration and causality analysis between energy consumption and growth in selected countries grouped as follows: high-income group; upper-middle-income group; lower-middle-income group; and low-income group. This way Yasar (2017) shows evidence of differences in the relationship between energy consumption and economic growth among country groups based on their income level. Sultan et al. (2019) pointed out that some of these researches have shown a positive association while others present a negative association and part of them an absence of this association. The different results may have happened due to the sample or the methodology used. It is important to mention the existence of sectoral GDP data, must present a greater correlation with the consumption of each sector than the overall GDP of a country and, therefore, it makes sense that the study of the relation between energy consumption and GDP be done separately for the different sectors of an economy.

Other works on this subject have contemplated the consumption of renewable energy and environmental deterioration. The renewable energy consumption has attracted the interest of many researchers in studies that relate energy consumption and economic growth. In a survey with a sample that included 38 countries, Bhattacharya et al. (2016) seek to verify the influence of renewable energy consumption on economic growth through a production function whose explanatory variables are the real gross fixed capital formation, labor force, renewable energy consumption and non-renewable energy consumption making it possible to verify the elasticities of these variables. In particular, the variable consumption of renewable and non-renewable energy in the GDP of the selected countries. Through this model, it is possible to infer the explanatory variable relevance for the production or the output verifying the statistical significance. In another research in the Bhattacharya et al. (2016) direction, Saad and Taleb (2018) make an analysis of the relationship studied by Bhattachatya et al. (2016) using a sample of 12 European countries with another methodology based on autoregressive vector models with error correction.

Other recent studies show interest in researches involving the environmental deterioration through carbon dioxide emission with energy consumption and economic growth. The

carbon dioxide emission variable is the endogenous variable in the establishment of stochastic relationships. Among these researches, the work of Cai et al. (2018) can be mentioned. Cai et al. (2018) investigate the relationship of these three variables in the G7 countries using cointegration tests, causality tests and the causal relationship between these variables. Another research that stands out is Raza et al. (2019) which deals with residential energy consumption and environmental degradation in two groups of developing countries or emerging economies, seeking to explain the emission of carbon dioxide through GDP, financial development, residential energy consumption per capita and the renewable energy consumption. In another work that can be mentioned, Khan et al. (2020) are interested in the relationship between energy consumption and economic growth with the environmental degradation. Khan et al. (2020) verify the relationship between these variables in Pakistan, in a research that aims to investigate this relationship using an ARDL model to verify the cointegration hypothesis and two stochastic models, one of linear regression and the other of error correction, to explain CO₂ emissions per capita through economic growth, coal, oil, and natural gas consumption.

Therefore, the existence of different and conflicting evidence regarding the growth of energy consumption and economic growth is clear.

3. METHODOLOGICAL APPROACH AND DATA USED

According to Böhringer and Rutherford (2008), there are two approaches for predicting energy demand: bottom-up and top-down. The bottom-up approach is based on the analysis of the end uses of electricity in each sector of an economy and the equipment of energy transformation into useful energy, an approach more associated with microeconomic models with a strong engineering base and study of the energy requirements of equipment and machines. This approach involves models that for the most part neglect the macroeconomic impact of energy policies while the top-down approach seeks to correlate the consumption of electric energy with scenario variables, such as GDP and population, and possibly with sector variables. Its main focus is the interaction between economy and energy from a macroeconomic perspective which considers initial market distortions, pecuniary externalities and income effects. Its main limitation is that in general, it does not incorporate details about the current and future technological possibilities that could be relevant for a better evaluation. The two views are valid, being necessary to choose the most appropriate to the objectives or adoption of a model that incorporates both. This work is aligned with the top-down approach. The income elasticity of consumption in the residential, industrial, commercial and other sectors was estimated through a simple linear regression model. The variables used were transformed by the logarithm, both the per capita energy consumption and per capita income given by GDP. Here GDP represents the independent variable and energy consumption is the dependent variable and it is assumed that the parameters consist of magnitudes that remain constant within the scope of a concrete phenomenon. The random term encompasses irrelevant factors not incorporated into the model due to the impossibility of observing it, or its non-observance. Additionally, the random term shows a deviation in relation to that observed to the dependent variable, that is, the difference

between the dependent variable estimated and the dependent variable observed. The model described above was estimated by the ordinary least squares method. The estimation method is described in the main econometrics' manuals such as Gujarati and Porter (2011) or Wooldridge (2014), among others, where one can have a better understanding of the method used here. According to Gauss and Markov Theorem, given some assumptions, it is possible to obtain the best non-biased linear estimators of parameters from ordinary least squares method. One of these parameters or coefficients is the one that has the greatest interest in this study, the coefficient of elasticity that indicates income elasticity of consumption, that is the object of this study.

In the estimation of the models, some important assumptions such as normality and stationarity are tested or verified, as well as the cointegration hypothesis between the two variables used in the models constructed to obtain the estimates of the elasticities. Besides checking the asymmetry and kurtosis coefficients the test used to verify the normality hypothesis of the model's stochastic terms was the Jarque-Bera test, according to the methodology shown in Gujarati and Porter (2011). The stationarity and cointegration tests are essential to choosing the most appropriate model to study the relationship between GDP and electric energy demand or the behavior of electric energy consumption in the world. The vector autoregressive models, or VARs, presented in the econometric literature by Sims (1980) is an appropriated system regression model to analyse the behavior of two or more economic variables. This way, these models can be used to understand the energy consumption behavior and for comparative analysis among models. The stationarity assumption is essential to guarantee the reliability of the vector autoregressive model (VAR) and the vector error correction model (VEC), which is a restrict VAR model for cointegrated variables. Thus, using the stationarity test for the variables selected is necessary. A stationary process has as its main characteristic the constancy of the mean, the variance and the autocorrelation structure, that is, these parameters do not change in the course of time. As mentioned in Gujarati and Porter (2011), the stationarity absence usually causes spurious regressions, even in large samples. This study uses the Augmented Dickey-Fuller (ADF) test to verify if the given variable is stationary or if a given time series is stationary or not. It is important to emphasize that the absence of stationarity of one variable can be easily corrected through differentiation processes. For further details of the ADF test, one can see Gujarati and Porter (2011).

Another important test for the variables analyzed is cointegration. It can be highlighted the cointegration in time series study is extremely relevant for the evaluation of economic time series, once it allows determining the relationships between the time series involved in a better way. The acceptance of the cointegration hypothesis between two variables has direct implication in the construction of regression models to explain one of these variables since a mechanism of error correction must be used in the model, since the variables share the same stochastic properties in the long run. Thus, the presence of cointegration makes the VEC model more suitable. In order to verify the existence of cointegration between the analyzed series, the Johansen cointegration test, widely used for this purpose, or the Engle-Granger test were used. These tests are detailed in Enders (2014) and Gujarati and Porter (2011) respectively. VAR, vector autoregressive, and VEC models, which are VAR models with

error correction mechanisms given by the cointegrating vector that involve the variables in question, were used here. The per capita energy consumption for residential, commercial, industrial and other sectors, and income, given by per capita GDP, are defined as autoregressive because they correlate the lagged past values of the variables analyzed with the present value of each variable, that is, in VAR models, where two or more variables are endogenous, are explained by other variables and these lagged variables. In this study, these lags were defined according to the Akaike criterion. The VAR and VEC models can be better detailed in Gujarati and Porter (2011) and Wooldridge (2014).

It is important to emphasize that in every application of the VAR model there will be one equation for GDP and another for energy consumption. However, as the interest of the analysis is only on the influence of GDP on consumption, only the results referring to this case will be pointed up. In addition, the use of VAR models is conditioned by the basic premise that the time series analyzed must be stationary otherwise the relationship can be spurious. When observing that the great majority of the time series was only stationary after their time series were differentiated. This differentiation softens the time series in order to avoid point peaks or that "delayed" impact causes distortions in the model. As observed, the VEC model is basically a VAR model in the first differences plus an error correction component. This error correction component indicates the speed of adjustment of any short-run imbalance toward a long-run equilibrium state. That is, while allowing the short-run dynamics this model restricts the long-run behavior of the variables, and is expected to converge to the cointegration relationships, which represents the long-term equilibrium relation. This allows the association of the two variables, that is, the two variables of interest for the study used in this work.

The data used for the accomplishment of the present study were sectorial electric consumption, GDP, sectoral GDPs and population. The International Energy Agency (IEA) was the source used to collect energy consumption data for the different sectors of the economy. The IEA is an autonomous organization linked to the Organization for Economic Cooperation and Development (OECD), which aims to ensure reliable, affordable and clean energy for its 29 member countries. Thus, due to the reliability and comprehensiveness of its data, it was the chosen source for the electric power consumption. On its website, it is possible to find annual electrical consumption data for the residential, commercial, industrial and "other" sectors for various countries in the world covering the period between 1990 and 2014. Revenue data, represented by GDP, was obtained through the World Bank website. The annual data was updated in early 2017 spanning from 1990 to 2014 for the 143 countries in the sample.

With the compiled data, annual consumption and per capita GDPs were calculated for each sector and each country analyzed. The per capita data is the best to be compared. Furthermore, it implicitly shows the population size which is an important variable in energy consumption studies. The use of general data, not per capita, would make it difficult to compare countries with different GDP values or consumption. Besides that, per capita GDP is usually more related to a country's level of social and economic development than its GDP. In the performance analyzes of the different models, the data logarithms were used. The log-log model is useful because the logarithmic conversion promotes the

transformation of a non-linear model into a linear one, making the analysis easier and comparing the parameters models linearization, which allows for obtaining the direct determination of the elasticities associated with the models.

Analyzing the information on the residential, commercial and industrial sectors it is possible to verify that normality can not be accepted at 10% for most data, between 80% and 90% of the countries in each sector. In the absence of a more suitable model, normality will be assumed for the application of the models. Regarding stationarity, this can not be rejected, considering a significance of 10%, for more than 50% of the countries in all sectors. The sector that presented the highest percentage of countries with stationarity was the industrial sector, with approximately 72%. Finally, it was verified that cointegration can not be rejected at 7% to 10% of countries in the “others” sector, 9% in industrial, 22.5% in residential and 36% in commercial.

The analysis of results obtained using the methodological approach with these data is presented in the next section.

4. ANALYSIS OF RESULTS OBTAINED

The results obtained for linear regression models and vector autoregressive models will be presented here. Two different approaches were used for comparison: individual results for all countries and results for groups of countries. The income elasticity estimates by the linear regression model, the error correction vector coefficients and the lagged energy values for the VEC model and p-value will be highlighted. It should be noted that the results for the VAR model are not displayed, since they were very similar to those of the VEC model.

As an initial hypothesis, it was expected that countries with similar economic and developmental levels would have similar results. As mentioned earlier there is a strong relationship between GDP and energy consumption, and several studies indicate that: as a country develops economically the tendency is for its income elasticity to decrease. Thus, it was assumed that the energy consumption in sites at the same economic moment would react in the same way to economic changes. In order to verify this hypothesis and to show the results in an illustrative way, maps will be presented for each sector. Thus, to present the results, figures were elaborated, which will be presented throughout the text. The elasticity coefficients were classified into classes or categories, differentiated by the intensity of the colors.

The map in Fig. 5 shows the results of the elasticity coefficient for the residential sector, where values of the income elasticity of residential energy consumption are observed between -0.1 and 0.4 for several countries in Europe and Canada. Values considered low, since a coefficient close to the unit for developing countries and lower than the unit for developed countries was expected, indicating that for these countries the GDP is not so determinant in residential electricity consumption. Besides that, considering the location of the countries that obtained this result differs from that expected. For most of these countries are well in the north of the planet, usually colder regions, which is possibly a more relevant factor for residential electricity consumption than economic development in these regions. It should be noted that the dispersion of the elasticity coefficients is high especially

among groups of countries and economic blocks not allowing the observance of similarities, which is evident in the results of Latin America, that presents all categories of income elasticity of electric energy consumption in the residential sector. The same occurs in the African continent. Although with lower values the same inference can be made for the European continent. Regarding homogeneous behavior or similarity situations it is possible to observe that for Brazil and China, countries belonging to BRICS block, the elasticities are close and relatively high, as expected for developing countries. Australia, the United States of America, Chile, and European countries, in turn, also meet expectations by presenting lower coefficients of income elasticity, as expected for more developed countries. Although not considered a developed country, it should be noted that Chile is the Latin American country with more similar behavior to that of developed countries. It should also be noted that the aforementioned inferences regarding income elasticities of residential electric energy consumption are conditioned to the statistical significance level in the estimate of the log-log linear regression model estimated to explain residential electricity consumption per capita through GDP per capita. Thus, the map presented in Fig. 5 should be analyzed simultaneously with the regression model F test, which represents its statistical significant test and can be represented by the analysis of variance F test result or by the respective p value, whose map with the results of countries is shown in Fig. 6. According to the values obtained, it is possible to affirm that the regression models for the great majority of the countries are statistically significant, proving the relation between GDP and consumption, making them possible to use for the inferences related to the coefficient of elasticity. However, for Russia, Canada and some European countries which presented very low values for elasticity, different from expected, p values of Fig. 6 indicate that the regression models should not be statistically significant.

Fig. 5. Residential Sector - Elasticity

Fig. 6. Residential Sector Regression Model - p value

Fig. 7. Residential Sector VEC Model - p-value

In addition to the results described above, the p values for the VEC model F test are shown in Fig. 7. The first finding from the map in Fig. 7 is that the p values are generally higher, which indicates that this model should not be statistically significant in a larger number of countries than the linear regression model. The model can be considered statistically significant at a level of 10% for approximately half of the countries analyzed, with p values below 1% in Brazil, Argentina, Mexico, India, China, among other countries. In a comparative analysis, the linear regression model presented p-value for the F test lower than the VEC model for 78% of the analyzed countries, indicating a higher statistical significance with this model.

Fig. 8 shows a map with the results income elasticity coefficients of electric energy consumption in the commercial sector. Values below 0.5 for elasticity for some European countries and Canada indicate small relevance of commercial GDP in the electric consumption of the commercial sector. This result is different from expected since this is a specific and perhaps a more appropriate economic indicator to explain this energy consumption. In commercial consumption, the elasticity coefficient dispersion is also high. In Latin America, two groups of countries with very similar elasticity coefficients can be observed, namely, the first group formed by Brazil, Argentina, Mexico and Central America, with values in the range [1.0; 1.4] and a second group formed by Ecuador, Peru, Bolivia, Chile and Paraguay, with higher values, always above 2. The other countries do not fit into any of these groups. In Europe, the behavior of the countries is more varied, but it is still possible to note groups with similar behavior: Portugal, Spain, Belgium, Italy, Albania, Bulgaria and Turkey present values in the range [2.0; 2.5]; France, Croatia, Greece, Holland, Germany, Poland, Russia, Iceland, Estonia, Romania and Ukraine have elasticities very close to unity; a third group presented values close to 0.8 and a fourth group presented the coefficients in the interval [0.4; 0.6]. The other European countries have more extreme values and do not fit into any of the identified groups. In Africa, countries have very dispersed or highly variable results. As can be seen in Fig. 9, according to the p values obtained in the linear regression models statistical significance tests used in the inferences of the elasticities, it is possible to infer that these models are statistically significant, with probability p values close to 1%, except the models to estimate Sweden and some countries in Asia and Africa. Unlike the residential sector, some very small elasticities were significant. This shows that

commercial GDP influences the electric consumption of the sector but does not have a great impact on its consumption.

Fig. 8. Commercial Sector - Elasticity

Fig. 9. Commercial Sector Regression Model - p value

Fig. 10. Commercial Sector VEC Model - p value

Fig. 11. Industrial Sector - Elasticity

Fig. 12. Industrial Sector Regression Model - p value

Fig. 13. Industrial Sector VEC Model - p value

The map presented in Fig. 10 shows the VEC models F test p values and their statistical significance. It can be observed that the values for Canada, Peru, Paraguay and some countries in Africa, Asia and Europe are above 15%, indicating that these models do not present statistical significance. On the other hand, they show p values below 1% for Brazil, Argentina, Bolivia, Mexico, India, China, most Central American countries, several European countries, among others. In a comparative analysis, the linear regression models presented F test p values lower than the VEC models for 87% of the analyzed countries, indicating a higher statistical significance.

The map presented in Fig. 11 shows the income elasticity of electric power consumption in the industrial sector, highlighting the low values, below 0.2, for Australia, the United States of America and some countries in Europe and Africa. This indicates that for these countries the industrial GDP is not so relevant in the electric consumption of the sector, a different result than expected since it is an advanced economic indicator of the sector. Another observation that stands out is the variability of the elasticity's coefficients, in all the continents and among all groups of countries whether they are developed or not. According to the map shown in Fig. 12, it can be inferred that the estimates of the regression models are statistically significant since the respective p values tests have statistical significance below 5%. It should be noted that for Paraguay, Australia, the United States and some countries in Europe and Africa, linear regression model estimates were spurious. As occurs with consumption in the residential sector, practically all the countries presented very low elasticity coefficients from the regression models estimated without presenting statistical significance. That is, according to these regression models, there is no significant relationship between each country's industrial GDP and their electric consumption of the sector, which differs from economic theory. Fig. 13 shows the F test probability p values of the VEC models, where high values can be observed for many countries, including all of North America, Australia and several countries in Latin America, Asia, Europe and Africa. Therefore, the assumption of the significance of VEC models for these countries is rejected. The same does not happen for Russia, India, China, Chile, Argentina, Bolivia, Venezuela, most Asian countries, among others. Comparing the significance obtained with each of the stochastic models involving the industrial consumption of electric energy and the industrial GDP through p value, it can be observed that in 76% of the countries the linear regression models presented F test p values lower than the VEC models, indicating a larger number of statistical significant stochastic models.

Fig. 14. Other Sector - Elasticity

Fig. 15. Other Sector Regression Model - p value

Fig. 16. Other Sector VEC Model - p value

Fig. 14 shows the map with the income elasticity results for the sector that groups all consumption that does not fall into any of the other economy sectors studied or "other" sector, that is, it does not belong to the residential, commercial or industrial sectors. By grouping consumptions of very diverse origins, like fishing and agriculture, the expectation is that it presents the incoherent results, example is given, dispersed elasticity coefficients and higher F test p values. The income elasticity coefficients values that can be observed are in the $[-0.9; 1.9]$ range, with statistical significance in all classes or categories. Thus, one can not assert that the previous hypothesis is the least homogeneous group. An interesting fact is that many countries in Europe have presented negative income elasticity coefficients, indicating that consumption in this category increases when GDP falls, and vice versa. It should be noted that Oceania and Asia have elasticities in the range $[0.0; 1.0]$, for most cases. The American continent, in turn, has the highest values of elasticity while Africa is the continent with the greatest dispersion among the income elasticity coefficients. It may be noted that in these other sectors set there seems to be a certain similarity of income elasticity among neighboring countries, or from the same region or continent. Possibly this is due to similar components in the other aggregate. Given the importance of the model significance, the map presented in Fig. 15 shows the statistical significance test p values of the consumption models estimated for the countries studied. According to the p values obtained, it is possible to state that the regression models for a large number of countries are statistically significant at a significance level of 1%. However, for Russia and some countries in Europe, Africa and Asia, the regression models demonstrated to be spurious. Finally, the F test p values of the VEC model are shown in Fig. 16. The first finding from the map is that the values are quite high for many countries,

especially in Europe, Africa and Latin America. This indicates that the model does not present statistical significance for these countries, with at least significance level of 15%. On the other hand, Fig. 16 map shows p values below 1% for Russia, Brazil, Australia, Canada, among others. Comparing the estimated models for other sectors, it is observed that the linear regression models presented the F test probability p values lower than the VEC models for 75% of the analyzed countries.

A new trend in energy integration has been consolidated in several parts of the world as a way to optimize existing generation projects and, hopefully, minimize the need to expand new plants that damage the environment, in order to meet the growing demand of countries that participate in this integration. It should be noted that the existing experiences in Mercosur are Itaipu (Brazil and Paraguay), Yacireta (Argentina and Paraguay) and Salto Grande (Argentina and Uruguay) hydroelectric plants. In addition, there is the Argentine gas pipeline in conjunction with Brazil, Chile and Uruguay, and the Bolivian gas pipeline with Argentina, Brazil and Chile. From this perspective, given the growing trend of energy integration, it is possible to say that a next step would be a joint plan for countries in the same region. In the current scenario, most of the existing interconnections only allow energy exchanges at times when some countries present surplus while others are in deficit. Faced with this, the joint plan would add many benefits, such as optimizing the number of plants to be installed, generating less impact on the environment. On the other hand, it is important to note that, despite the benefits, the implementation of this type of energy integration faces several barriers, especially political ones. As an example, it is possible to cite the case of Bolivia, which nationalized the Petrobras facilities in its territory and reduced the shipment of natural gas to Brazil and Argentina. Given this, two blocks that have great potential for integration are Europe and Latin America.

5. CONCLUSION AND FINAL COMMENTS

The objective of this study was to determine income elasticities of residential, commercial, industrial and other sectors in 143 countries around the world. Thus, it can be said that the goal has been achieved. Given that, in addition to estimating the elasticities coefficients, the relationship between the variables was verified through regression and autoregressive models, VAR and VEC, and the statistical significance of the estimates.

Analyzing the relationship between the per capita electricity consumption and the per capita GDP of the 143 countries over 24 years, there is a tendency to decelerate consumption growth and, in some cases, even a decrease in demand per inhabitant. It should be noted that the relationship between consumption and GDP was expected to be similar for countries with similar levels of economic development and/or near location. However, which made sense a priori, it was not possible to find patterns when analyzing the maps with the graphical representation of the results and detailed maps for European and Latin American countries. The study thus indicates that this hypothesis, often used in demand forecasts to compare the situation of the country with that of nearby regions and with a similar development level, can not be proven.

Despite the differences and lack of an observed pattern, the results obtained for the aggregated analyzes were satisfactory, always obtaining at least one statistically significant model, with low p values. This indicates that aggregate planning makes sense and can enhance the benefits of energy integration. This would occur by reducing the need for new generation capacity when exploring different individual behaviors that, when aggregated, tend to be well behaved.

Another point of relevance was the difference between the income elasticity of energy consumption obtained in the analysis of the developed countries, more specifically in Europe, and of the developing countries, represented in the detailed analysis by Latin America. The difference was even greater in the residential and industrial sectors, in which the aggregate elasticity of Europe was practically one-third of that found for Latin America. This behavior was already somewhat expected, given the trend of increasing energy efficiency and conscious consumption, which have been encouraging the slowdown of growth and even reduction of demand, so that it varies less than GDP. On the other hand, in developing countries, these trends are still of little relevance and do not have such an impact on the relationship between GDP and consumption, so that changes in the economy generate even greater fluctuations in electricity demand. Moreover, it should be noted that the sector designated as "others" in Europe seems to have a very divergent behavior from one country to another, presenting non-significant linear regression models but being well represented by the VEC model. In Latin America, this category appears to be more similar among countries, with a significant regression of less than 0.001% and a high elasticity of more than 2.

Finally, for future studies on the subject the performance of consumption forecast models can be verified and new explanatory variables, such as electric tariff, can be added to the models used here, as well as using a longer analysis period since the size of the sample used compromises the robustness of the results obtained here. It would be interesting to carry out a more in-depth study of the correlation between the different consumption sectors and the variability of the long-run forecasts by testing the basic assumptions of regression analysis and using heteroscedastic models if necessary. In addition, other methods of statistical inference must be considered so that more robust results may be obtained. Besides that, it is suggested that the policy implications related to green energy or renewable energy be considered in a sequel of this or in future works on this theme. Also new studies can contemplate the behavior of different users for each country chosen regarding the commercial and non-commercial energy consumption patterns as well as industrial and non-industrial or residential or non-residential energy consumption patterns.

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