

Energy production and trade openness: Assessing economic growth, CO₂ emissions and the applicability of the cointegration analysis

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ABSTRACT

The relationship between economic activities such as energy production, trade, and economic growth affects all areas of human life in terms of well-being, as well as a country's economic activities. In this study, we investigate these relationships using cointegration regression methods (FMOLS - fully modified ordinary least square and DOLS - dynamic ordinary least squares), we use the electricity production (hydro, natural gas and renewables), trade opening, GDP, and CO₂ emissions to establish causality. We found that electricity generation, GDP and trade liberalization have both positive and negative effects on Brazil's economy. We also discovered a bi-directional causality between trade openness and all the energies produced in Brazil. Separately, we observed that GDP, hydropower, and renewables have negative effects on the CO₂ emissions model, while only emissions of pollution and trade openness have positive effects on the economic growth model. These results have important policy implications for the Brazilian economy that does not support appropriate long-term sustainable development strategies. Consequently, policymakers should consider implementing appropriate management capacity to encourage the use of renewable energy and to benefit from the positive effects of economic growth and environmental policies to control the pollution rate through the potential of available natural resources. Our findings are not motivated by discrepancies or sample selection and survive multiple specifications, allowing to observe the relationship with great accuracy. Some diagnostic tests have been applied to show that it is not misleading.

1. Introduction

Brazil is the main intermediary development country in Latin America. This giant from South America began the 1990s undergoing profound transformations. The recent democracy initiated after a long period of the dictatorial government that lasted more than twenty years would lead to economic, social and environmental transformations. A holder of abundant natural resources and strategic companies in agricultural and mineral commodities, textiles, oil extraction, engineering and other important economic sectors, energy consumption has increased concomitantly with its economic growth. However, the low savings level around 20% did not allow to leverage the level of aggregate investment in infrastructure, for example, the energy sector reduced investments by more than 2% of the decade's GDP from 1970 to 0.70% in 2016, with an estimated reduction to (0.41%) in 2017 [1]. The main hydro source electricity development potential remained unchanged at

the expense of new thermo-power plants until 2002 and was marked by a serious energy crisis especially caused by the lack of investments in the expansion of generation capacity and aggravated by climatic problems [2,3].

The continental dimension of Brazil and its large population implies a high degree of social, economic and environmental complexity, given an urbanization index of around 86% [1]. In the social area, investments starting 2005 ensured important income transfer programs such as (Bolsa Família and Luz para Todos), these programs reached a large proportion of people living with extreme poverty. At the end of 2014, around 30 million people were outside the extreme poverty line and in 2015 almost 100% of the population had access to electricity services in Brazil. This significant progress directly impacted the Gini coefficient, which indicated 0.53 [4].

However, the problem now is not just electricity generation because it needs to grow. But, the problematic political, economic,

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environmental and social scenario is added. For example, the high unemployment rate, the reduction in industrial production and the low level of consumption were observed due to several economic uncertainties. Thus, Brazil remains trapped in the middle-income level for several decades and is unable to transition to a higher income level together with developed countries. In fact, Brazil for over half a century has accumulated large macroeconomic imbalances that have increased income inequality and the deterioration of environmental typical of developing country's status [1]. Therefore, reduce inequalities and promote economic growth and environmental quality, that is, making sustainable use of its resources to ensure economic growth with less environmental impact and equity of income distribution is the great challenge of Brazil.

Several studies have been shown how economic development results in negative environmental impacts and, therefore, presents great challenges to reduce external factors negatively associated with social, environmental and economic activities [5]. For example, the relationship between carbon dioxide emissions, generation of electricity and economic growth has been widely studied in all around the world. The main researches are in the context of the use of primary energy source, that uses crude oil, coal and natural gas and are divided into three main theoretical fields: in the first field, the nexus of energy growth is used to observe the contribution of energy as a productive factor of the economy and originates from the seminal study by Ref. [6]; in the second field, environmental variables are added to the energy and growth nexus, mainly to test the validity of the Kuznets environmental curve - EKC, also started from another seminal research by Ref. [7]; the third field, is the combination of these two lines of research that links the dynamic relationship between economic growth, the environment, and total energy consumption, namely, energy-growth-environment nexus. The objective of the third theoretical field is to analyze the contribution of economic growth and the use of energy as a driver of CO₂ emissions in the environment ([8–10]).

In this research, we put our work in the third frame to analyze the present study. In Brazil, empirical evidence is limited and controversial and ambiguous. For example, major emissions have historically been concentrated in agriculture, forestry, and other land-related uses. Mainly to deforestation, cropping, and livestock. While, in 2014, those related to energy from greenhouse gas emissions - GHG, were 2.4 tons of CO₂ emissions [4]. Electricity is not a primary source and its generation, its emissions, must be remembered as economic processes (e.g. power plants that require fossil fuels to generate electricity, and GHGs emissions, therefore, are inherent in their operation). Indeed, other technologies usually called as green still present CO₂ emissions that, if not produced in the generation of the electricity itself, play an important role in the upstream and downstream stages of the process (e.g. power plant construction, obtainment of fuel, plant operation, wastes treatment, etc.) [11].

Brazil's electricity generation is 158.798.566 kW (kW) of installed capacity and the addition of 17.152,466 kW in generation capacity is expected from the 205 under-construction projects and another 377 whose constructions have not yet been started. The structure of electricity generation is the largest in Latin America and is distributed as follows: 64.48% is formed by hydro; 17.15% is from fossil sources; 1.19% is nuclear energy; renewable electricity accounts for 8.82% biomass, 7.66% wind and 0.7% solar energy (Aneel [12]). Overall, energy production in Brazil increased concurrently with the growth of the economy, and both appear as the main players for the growth of CO₂ emissions in the period under analysis.

The historical series shows that hydropower is the main source of electricity in Brazil (see Fig. 1). However, in 2001 the system collapsed occurring blackout in the regions of greater urban concentration, where the industrialists of Brazil are also located. These events occurred as a result of the lack of investments to increase the electricity generation capacity associated with a severe water crisis in this period. Another important factor is the timid growth of other energy sources (e.g.,

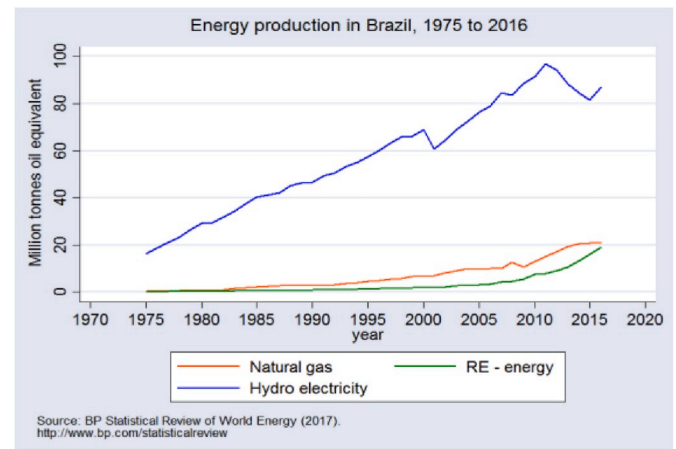


Fig. 1. Energy production from 1975 to 2016.

natural gas production and renewable electricity) compared to the growth of CO₂ emissions in the same period. Figs. 1–3 show the energy generation, GDP and CO₂ emissions, respectively.

Although, the level of economic growth is associated with energy consumption. Rationally, we believe that an economy will be more openness when the country becomes more polluted? This is not a reasonable assumption for countries like Brazil, where more than 60% of its electricity base is hydropower [11]. The purpose of this study is to empirically investigate these relationships and seek to achieve the objective of three ways. Firstly, we, use estimation techniques robust to apply parametric and non-parametric models DOLS (Dynamic ordinary least squares) and FMOLS (Fully modified ordinary least squares), to explain the relationship in the long-term. Secondly, most of the existing studies focus on time series analysis on Latin America are focused on individual countries. Specifically, there are no empirical studies on investigating causality between energy production, economic growth, trade openness and CO₂ emissions for Brazil individually. Thirdly, we believe that more hard models can provide better analyzes due to problems of endogeneity, bias due to sample size and serial correlation. Also, our article mainly contributes to the literature that investigates the effect of electricity generation on economic performance and pollutant emissions of these energetic sources, and trade.

The next section presents the literature review; the methodological process is presented in the third section; the empirical finding is discussed in the fourth section; the last section brings together the overall results and policy implications.

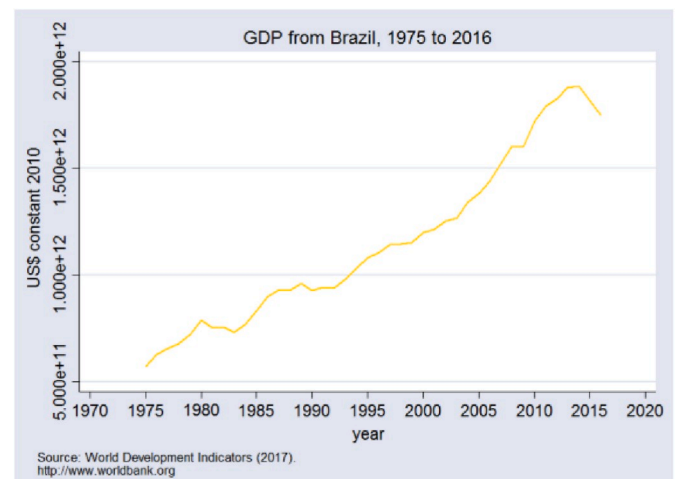


Fig. 2. Gross domestic product (GDP) from 1975 to 2016.

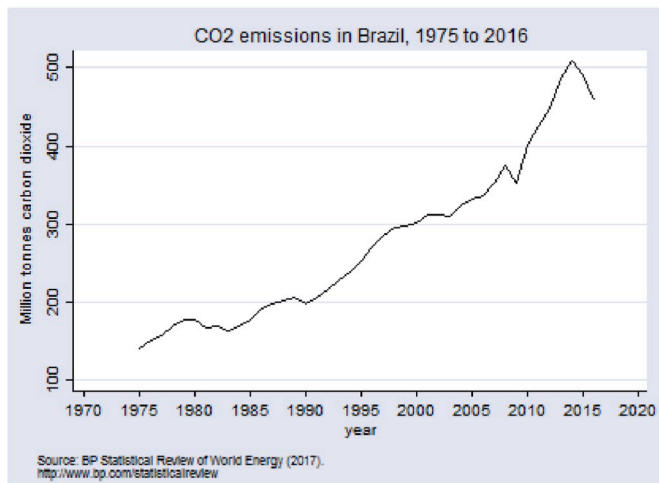


Fig. 3. CO2 emissions from 1975 to 2016.

2. Literature review

The researches of the relationships established between electricity generation and the economic growth nexus is not a recent theme in the literature and the relationships have been investigated from the perspective of the energy consumption–economic growth nexus [13]. This is particularly due to the important role that energy consumption plays in economic growth and principally because the interaction invokes essential policy implications [14]. However, the vast literature focuses especially on causality relationship and highlights four possible hypotheses:

Hypothesis (a), the unilateral type that can occur from unidirectional causality relationship of energy consumption running for economic growth “Energy → GDP”, *growth hypothesis*;

Hypothesis (b), contrary to the previous hypothesis, variations in economic growth may cause impacts that affect energy consumption “GDP → Energy”, *conservation hypothesis*;

Hypothesis (c), occurs when energy consumption and economic growth are independent “Energy \nleftrightarrow PIB”, *neutrality hypothesis*;

Hypothesis (d), when is identified the existence of bi-directional of causality relationship between energy consumption and economic growth “Energy \leftrightarrow PIB”, *feedback hypothesis*;

The studies on the energy-growth-environment nexus found of this literature demonstrate the absence of consensus about the directionality of causality among them. For example, ref. [15] found significant evidence that the share of renewable energy in electricity output is a potential driver for reducing the carbon emissions in electricity, which tends to be large at the early stage of European economic development. Ref. [16] studied the nexus of electricity consumption, economic growth and CO2 emissions in the BRICS countries. The results showed that electricity consumption is found to Granger cause CO2 emissions in India, whilst there is no Granger causality between electricity consumption and CO2 emissions in Brazil. Ref. [17] found evidence of electricity consumption and economic growth have a positive long-run relationship with carbon dioxide (CO2) emissions for Gulf Cooperation Council Countries. Ref. [18] findings, in the long-run, there appears to be a bidirectional causality between electricity consumption (renewable and non-renewable) and CO2 emissions for the MENA region. Whilst, to Ref. [19] the economic activity effect is the most important contributor to increase CO2 emissions from electricity generation to the same region. Ref. [20] found a relationship between electricity generation, economic growth and CO2 emissions to South American countries applying a set panel data.

Ref. [21] used FMOLS and DOLS and CCR estimates and confirmed economic growth driven by electricity consumption for Nigeria. These

authors also found unidirectional causality of economic growth for electricity consumption with the level of urbanization, in the long run, impeding economic growth. Recently ref. [22] found evidence of an asymmetric effect of per capita consumption of natural gas on economic growth and CO2 emissions for a panel of African countries. Ref. [23] examined the impact of renewable energy and financial development on CO2 emissions for 24 countries in the Middle East and MENA region, their results demonstrated only a slight influence of financial development on CO2 emissions. In turn, ref. [24] examining the relationship between CO2 emissions, renewable energy and trade noted that both renewables and trade affect increasing CO2 emissions in the long run in China.

Ref. [25] reported new findings on the determinants of CO2 emissions for Turkey, using the role of trade for this, and found a reduction in CO2 emissions as GDP increased. They also found evidence that increased imports raised CO2 emissions in the long run. While the exports have effects negative on pollution emissions. Already, Ref. [26] examining the effect of international trade on CO2 emissions from 65 countries found evidence that the exports and the imports exhibit negative effects on CO2 emissions. Whilst ref. [27] found a negative association of renewables with pollution emissions and a positive association with production for high-income countries using a cointegration panel. And finally, ref. [28] investigated energy consumption, CO2 emissions, trade and economic growth for Kuwait and found empirical evidence that CO2 emissions and energy consumption accelerate economic growth, they also noted that an increase in CO2 emissions also increases energy consumption.

Therefore, as can be noted the several papers shown that have been results varied as well as to the political implications associated with the causal relationship of energy consumption and economic growth and to relationships among energy-growth-environment nexus. Table A1 and A2 summarize the main researches by country, by authors, by methodologies, by periods of analysis and by the type of results obtained and published recently by the specialized literature.

3. Empirical analysis

3.1. Data and source

In our models, we use data to cover the period 1975 to 2016 collected from the World Bank Development Indicators (WDI) online databases (www.worldbank.org) and BP Statistical Review of World Energy, available in (<http://www.bp.com/statisticalreview>). Six variables were used in this research to examine the impact of energy, and trade openness on CO2 emissions and economic growth in Brazil. These variables include, (a) Real gross domestic product per capita in international US\$ constant 2010 (GDP); (b) CO2 emissions in million tonnes of dioxide carbon (PCO2); (c) Hydropower in million tonnes of oil equivalent (Hydro); (d) Natural gas in million tonnes of oil equivalent (NatG); (e) Renewable energy in million tonnes of oil equivalent (RE)¹; and (f) Trade openness, equivalent the import + export/GPD (OPen)². All these variables were converted to the natural logarithm to reduce non-normality and heteroscedasticity.

¹ Its based on gross generation from renewable sources including wind, geothermal, solar, biomass and waste, and not accounting for cross-border electricity supply.

² Represent the proportion of Imports and exports of goods and services comprise all transactions between residents of a country and the rest of the world involving a change of ownership from nonresidents to residents of general merchandise, nonmonetary gold, and services. Data are in US\$ international dollars.

3.2. Model specification

To these analyses, firstly two models were employed: Model (a) - economic growth and model (b) - CO2 emissions. equations (1) and (2) represent the functional specifications for both models. All variables are in natural logarithms and the functional form of the model will be as follows:

$$\ln(GDP_t) = \alpha_0 + \alpha_1 \ln(PCO2_t) + \alpha_2 \ln(Hydro_t) + \alpha_3 \ln(NatG_t) + \alpha_4 \ln(RE_t) + \alpha_5 \ln(OPen_t) + \varepsilon_{1t} \quad (1)$$

Where GDP is the gross domestic product; PCO2 is pollution by CO2 emissions; Hydro is the generation of hydropower; NatG is the production of natural gas; RE is renewable energy and Open is the trade openness that gives greater competitiveness to trade. α_0 denote the intercept, ε_{1t} are the stochastic disturbance terms.

The level of energy consumption is presented by the literature as the main vector of the growth of a country's production. This is revealed by the need to run all the technological equipment to realize the production that is dependent on energy consumption. Thus, considering that the level of economic growth, especially the intermediate economy countries, this can influence CO2 emissions. A second model was defined as having the dependent variable the level of pollution. That is:

$$\ln(PCO2_t) = \beta_0 + \beta_1 \ln(GDP_t) + \beta_2 \ln(Hydro_t) + \beta_3 \ln(NatG_t) + \beta_4 \ln(RE_t) + \beta_5 \ln(OPen_t) + \varepsilon_{2t} \quad (2)$$

Where the level of pollution (PCO2 - dependent variable) is regressed over energy variables, economic growth, and trade openness (explanatory variables). The latter variable is associated with industrial and trade structure and a higher intensity of carbon dioxide emissions can be identified. β_0 denote the intercept, ε_{2t} are the stochastic disturbance terms. In this order, the relationship between the emission of carbon dioxide and the level of economic growth for Brazil is examined.

Indeed, we provide an appendix of long-run analysis by re-running the model using different dependent variables. This is due to is allowed to treat all variables as endogenous variables. Subsequently, we have resolved to test each of the energy variables and trade openness as a dependent variable as a benchmark over all the explanatory variables as follows:

$$\ln(Hydro_t) = \phi_0 + \phi_1 \ln(GDP_t) + \phi_2 \ln(PCO2_t) + \phi_3 \ln(NatG_t) + \phi_4 \ln(RE_t) + \phi_5 \ln(OPen_t) + \varepsilon_{3t} \quad (3)$$

$$\ln(NatG_t) = \gamma_0 + \gamma_1 \ln(GDP_t) + \gamma_2 \ln(PCO2_t) + \gamma_3 \ln(Hydro_t) + \gamma_4 \ln(RE_t) + \gamma_5 \ln(OPen_t) + \varepsilon_{4t} \quad (4)$$

$$\ln(RE_t) = \lambda_0 + \lambda_1 \ln(GDP_t) + \lambda_2 \ln(PCO2_t) + \lambda_3 \ln(Hydro_t) + \lambda_4 \ln(NatG_t) + \lambda_5 \ln(OPen_t) + \varepsilon_{5t} \quad (5)$$

$$\ln(OPen_t) = \psi_0 + \psi_1 \ln(GDP_t) + \psi_2 \ln(PCO2_t) + \psi_3 \ln(Hydro_t) + \psi_4 \ln(NatG_t) + \psi_5 \ln(RE_t) + \varepsilon_{6t} \quad (6)$$

Where, $\phi_0, \gamma_0, \lambda_0$ and ψ_0 denote the intercept $\varepsilon_{3t}, \varepsilon_{4t}, \varepsilon_{5t}$ and ε_{6t} are the stochastic disturbance terms, assuming they are normally distributed and $\phi_1, \gamma_1, \lambda_1$ and ψ_1 with $i = 1, \dots, n$, denote the coefficients of the explanatory variables.

3.3. Stationarity tests

A fundamental purpose of using a unit root test is to control whether or not each time-series data contain unit root [29]. To check the stationarity of variables, we conduct two unit root tests. The unit-based econometric technique was adopted based on the test augmented Dickey and Fuller [30] and Phillips and Perron [31]. To examine the non-stationarity property of the time series variables, in level and 1st

difference, the ADF and PP test will be applied. The ADF e PP test could be expressed as equations (7) and (8), respectively:

$$\Delta X_t = \theta + (\rho - 1)X_{t-1} + \phi T + \delta \Delta X_{t-1} + \mu_t, \quad (7)$$

$$\Delta X_t = \theta + (\rho - 1)X_{t-1} + \phi \left(t - \frac{T}{2} \right) + \delta \Delta X_{t-1} + \mu_t, \quad (8)$$

Where X_t represent variable series, Δ represents the first differences, and the terms of the lagged difference are included to correct the series correlations of the perturbation terms. The SIC - Schwarz information criterion is used to select lagged differences. When $\theta = 0$, the series X_t has a unit root, technically is I (1) and, is governed by a stochastic tendency. If the result indicates that the variable (time series) selected is integrated of order I (1), we can conclude that the series is stationary and must start for the cointegration test of the variables.

3.4. Cointegration test

The application of the cointegration test is very important because this procedure allows the researcher to examine the relationships between the variables. The existence of cointegration indicates that there is a balance between the variables of the model in the long run. Besides, as to affirm ref. [32] the cointegration test can still serve as a guarantee of consistent results when using the ordinary least square (OLS) method to estimate the coefficients. There are several methods to test the cointegration in the literature.

However, the Johansen's cointegration test implies the estimation of an autoregressive vector model, known as VAR, including values at levels as well as differences of non-stationary variables [33]. At this stage, a VAR model is configured to determine the optimal lag length and the SIC - Schwarz information criterion is applied to optimize lag lengths for the time series. The Johansen test equation is described as follows:

$$\Delta X_t = \tau_1 \Delta X_{t-1} + \dots + \tau_{k-1} \Delta X_{t-k+1} + \pi X_{t-k} + \varepsilon \quad (9)$$

Where ε is the random variable, τ_1 and π demonstrates the OLS parameter matrices, πX_{t-k} examines the linear combinations of levels of the X_t and the matrix π has the information about the long-term properties. When the classification of the matrix π is equal to zero, no series can be expressed as a linear combination of the remaining series. But, the long-term cointegration can be confirmed when the degree of the matrix coefficient π is greater than 1 [33]. The literature mentions two statistics for determining the degree of the matrix coefficient or the number of cointegration relationships. These statistics are obtained through the use of two likelihood ratio (LR) tests - the Trace statistic and Max-Eigen statistic whose application examines the null hypothesis on the number of cointegration ratios r versus the alternative hypothesis $r + 1$. The presence of cointegration is required for the application of regression methods using FMOLS and DOLS models. Therefore, based on Trace statistic and Max-Eigen statistic statistics the rejection of the null hypothesis is necessary with a significance level of 5% for the confirmation of long-term cointegration between the model series [33]. Thus, if a cointegrating relationship between the series is found, the next step is to estimate the long-run parameters.

3.5. Long-run estimates

Due to the great difficulty for the researchers to decide on the results of cointegration between the time series in the long term. Another cointegration test proposed by Ref. [34] was developed and used to eliminate errors in the Ordinary Least Squares (OLS) estimates. While Phillips and Hansen [34] were heavily criticized by Refs. [35] who applied FMOLS for long-term estimates comparing the estimates obtained by an Unrestricted Error Correction Mechanism (UECM), Stock and Watson [36] developed a parametric method, Dynamic OLS (DOLS)

that has the power to control the endogenous effect. In contrast, FMOLS (fully modified OLS) is a non-parametric method that solves the problem of serial correlation [37].

Both methods use leads and lags of the variables in an OLS cointegration regression. One of the main advantages of using FMOLS and DOLS models is that these estimators are free of endogeneity problems, bias due to sample size and serial correlation. In this sense, the robustness of the coefficients can be reached as these methods manage to control endogeneity and serial correlation, as a corollary can be obtained asymptotically unbiased estimates in the long term [38]. The estimates with cointegration regression FMOLS and DOLS that control correlation and the endogeneity problem can be explained as follows ([8,33,39]):

$$\hat{\beta}_{FMOLS \text{ or } DOLS}^* = N^{-1} \sum_{i=1}^N \hat{\beta}_{FMOLS \text{ or } DOLS}^* \quad (10)$$

Where $\hat{\beta}_{FMOLS \text{ or } DOLS}^*$ are estimators FMOLS and DOLS conventionally. Moreover, the t -statistic associated the estimators can be obtained as:

$$t_{\hat{\beta}_{FMOLS, DOLS}^*} = N^{-1/2} \sum_{i=1}^N \frac{\hat{\beta}_{FMOLS, DOLS}^*}{\hat{\beta}_{FMOLS, DOLS}^*} \quad (11)$$

3.6. Wald's granger causality tests

This article applies the Toda-Yamamoto approach to test for the presence of Granger-sense of causality. One of the uniqueness of this approach is that it can be applied without the knowledge of cointegration. In this case, the presence of cointegration is not necessarily required for the application or use of the modified Wald test for an autoregressive model proposed by Toda and Yamamoto [40]. This technique is very effective for examining economic growth in an energy production structure. Therefore, this procedure can be used in level VARs models, regardless of whether the series are integrated, cointegrated or not. That is if the time series are I (0) or I (1). However, we must identify the order of integration of the time series. In this specific case, the results obtained from the ADF and PP tests previously mentioned in section 3.2.2 dealing with the unit root analysis of the time series used in this study will be used.

Specifically, this test involves two steps: The first step identifies the maximum order of integration (d) and lags length ideal (k) of the variables. The second step describes the result of the VAR (k) causality test through the Granger causality Wald test. For bivariate association (Y, X), the Toda and Yamamoto [40] test can be expressed as follows ([33,41, 42]):

$$Y_t = \alpha_0 + \sum_{i=1}^k b_{1i} \cdot Y_{t-i} + \sum_{i=k+1}^{k+u} b_{2i} \cdot Y_{t-i} + \sum_{i=1}^k c_{1i} \cdot X_{t-i} + \sum_{i=k+1}^{k+d_{\max}} c_{2i} \cdot X_{t-i} + e_{1t} \quad (12)$$

$$Z_t = d_0 + \sum_{i=1}^k e_{1i} \cdot X_{t-i} + \sum_{i=k+1}^{k+u} e_{2i} \cdot X_{t-i} + \sum_{i=1}^k f_{1i} \cdot Y_{t-i} + \sum_{i=k+1}^{k+d_{\max}} f_{2i} \cdot Y_{t-i} + e_{1t} \quad (13)$$

Where Y_t is a dependent variable, X_t represents the independent variables, e_{1t} in (8) and e_{1t} in (9) are the residuals of the models. The statistics χ^2 standard is used for applying the Wald test to the first k coefficient of the matrices. If $c_1 = \text{var}(c_{11}, c_{12}, \dots, c_{1k})$ represents the vector of the first VAR coefficients. The null hypothesis X does not cause Y is expressed as:

$$H_0 : c_{1i} = 0, i = 1, \dots, k \quad (14)$$

Likewise, the second null hypothesis that Y does not cause X is as follows:

$$H_0 : f_{1i} = 0, i = 1, \dots, k \quad (15)$$

Wald's Granger causality test tests the hypotheses and the calculated Wald statistic has an asymptotic distribution χ^2 with k degrees of freedom ([33,41]).

4. Empirical results and discussions

The first result of this investigation is the examination of the root of the unit. In other words, it refers to the issue of stationarity of time-series. For this, all series were analyzed with the inclusion of intercept and linear trends. According to the tests (ADF) and (PP), the existence of a unit root at levels and stationarity in first differences, they prove that the time series are integrated into order 1 or are I (1) at level 1% significance. The results are shown in Table 1.

The second result obtained by the study is the cointegration analysis. i.e., the issue cointegration of the time series. However, to apply the cointegration test and later to analyze the direction of causality, it is necessary to examine the lag length determination first. It is based on the appropriate lag length selection procedure that is based on the following selection criteria: (LR - sequential modified LR test statistic (each test at 5% level); - Hannan-Quinn information criterion; SC - Schwarz information criterion). This procedure is necessary because the results become biased if an inappropriate selection of lag length occurs [33]. The selection result indicates that the appropriate lag length is three as shown in Table 2.

After identifying the appropriate lag length, the Johansen cointegration test was applied. Under this cointegration test, the maximum eigenvalue that has the null hypothesis $H_0: r = r$ against the alternative hypothesis $H_1: r > r$, and the tracking test that has the null hypothesis $H_0: r \leq r$ against the hypothesis alternative $H_1: r > r$ that examines the cointegration relationship for the variables used. In this sense, for the sake of brevity, the estimated long-term coefficients terms that closely match those predicted by economic theory in magnitude and sign must be adopted as a cointegration model. In this case, for both tests used in this study, the null hypothesis of cointegration, none, 1, 2, 3 and 4 are rejected and the 5 cointegration equation does not reject the null. The result indicates that there are cointegration relationships between model variables (see Table 3).

Indeed, the results show the cointegration relationship between the variables in the considered period, although, there is one model, whose doesn't reject the null hypothesis. This result implies that there is some kind of co-movement between these series in the long run, as the convergence is observed. This allowed determining the long-term coefficient between the variables by the FMOLS and DOLS methods as tools to investigate the magnitude of the cointegration relationship between the time-series [21]. Therefore, our next step was to estimate equations (1) and (2).

In this case, the tool econometric regresses cointegration by implementing two completely efficient estimates: FMOLS – using correction to eliminate problems among the error of the cointegration and the regressor. Whilst, DOLS – are conditioned to absorb the long-term correlation, indeed, the long-term covariance is calculated with a pre-upgrade strategy and kernel functions; the standard errors are consistent with heteroskedasticity and autocorrelation. In the end, it produces regression of the cointegration model. The model's empirical results with cointegration regression FMOLS and DOLS are in harmony in terms of statistical significance and signal orientation (see Tables 4 and 5).

Table 4 reports that when the dependent variable is economic growth (equation (1)), with FMOLS estimator - model (a), for the hydropower, natural gas, and renewable electricity variables, the coefficients of direct effects is negative (e.g., these variables have relationship negatively with GDP in -0,87%, -0,05% and -0,34%), respectively, at 1% significance level. In other words, in the long run, the coefficients are perfectly inelastic to the GDP variation in Brazil, but

Table 1
Unit root test.

Variable	augmented Dickey-Fuller (ADF)				Phillips-Perron (PP)			
	Level	p-value	1st diff.	p-value	Level	p-value	1st diff.	p-value
LGDP	−2.444	0.352	−4.868 ^a	0.001	−2.127	0.515	−4.784 ^a	0.002
LPCO ₂	−1.817	0.677	−4.684 ^a	0.002	−2.049	0.557	−4.684 ^a	0.002
LHydro	−2.896	0.174	−5.590 ^a	0.000	−2.878	0.179	−5.532 ^a	0.000
LNatG	−2.805	0.204	−6.445 ^a	0.000	−2.564	0.297	−6.444 ^a	0.000
LRE	0.046	0.995	−6.758 ^a	0.000	−0.054	0.994	−6.748 ^a	0.000
LOPen	−1.372	0.586	−5.373 ^a	0.000	−2.041	0.562	−5.373 ^a	0.000

Note: ^a and ^b indicate that unit root in the first differences are rejected at 1% and 2% level, respectively; The null hypotheses of the test have a unit root that was decided upon following a visual inspection of the series; Lag length = 1 and with the constant, linear trend; The software EViews11 served to calculate ADF and PP.

with the coefficients of CO₂ emissions and trade openness perfectly elastic. This finding suggests that although pollution emissions and trade openness benefits an increase in the GDP, the other variables suffer from it. The estimate with DOLS (model (a1)) has similar results to the FMOLS results (model (a)) (see Table 4).

Table 5 reports the estimates of the implicit direct effect of electricity production, GDP and trade openness on CO₂ emissions to Brazil. This is when the dependent variable is the CO₂ emissions (equation (2)), FMOLS estimator – Model (b), the coefficient of the direct effect of natural gas production and trade openness is positive and statistically significant. Therefore, the elasticities are elastic and demonstrate those emissions of carbon dioxide increase with the increase in natural gas production and trade openness. Already the coefficient of the direct effect of GDP, hydropower and renewable electricity is negative and implies that an increase of 1% in GDP and the production of these energies, the inelasticity's demonstrate the reduction of CO₂ emissions by −1.57%, −5, 43% and −0.24%, respectively.

When CO₂ emissions are estimated using DOLS, model (b1), the only series that returned a negative value was trade openness at the 1% significance level, whilst, the GDP and natural gas were not significant. In this case, long-term trade liberalization causes a reduction of 0.67% in CO₂ emissions. The other remaining variables (hydropower and renewable energy) (as opposed to the FMOLS model) have positive long-term relationships with CO₂ emissions. In other words, these series are elastic and show that a 1% increase in GDP and the generation of these energies causes increases of (0.62% and 0.45%) in CO₂ emissions, respectively.

In the overall, cointegration regressions showed that the FMOLS structure returns the best results in terms of mitigating pollution

Table 2
VAR lag order selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	143.100	NA	3.56e-11	−7.030	−6.774	−6.938
1	370.095	372.504	2.03e-15	−16.825	−15.033 ^{sc}	−16.182
2	426.470	75.167	8.19e16	−17.870	−14.543	−16.676
3	482.624	57.592 ^{sc}	4.27e-16 ^{sc}	−18.903 ^{sc}	−14.041	−17.159 ^{sc}

Table 3
Johansen tests for cointegration.

Series: LGDP, LPCO ₂ , LHydro, LNatG, LRE, LOpen							Results
Hypothesized no. of CE(s)	Trace statistics	0.05% Critical value	p-value ^b	Max-Eigen Statistic	0.05% Critical value	p-value ^b	
none ^a	239.813	117.708	0.000	65.226	44.497	0.001	Reject H ₀
At most 1 ^a	174.587	88.803	0.000	64.195	38.331	0.000	Reject H ₀
At most 2 ^a	110.492	63.876	0.000	43.341	32.118	0.014	Reject H ₀
At most 3 ^a	67.150	42.915	0.000	36.971	25.823	0.011	Reject H ₀
At most 4 ^a	30.179	25.872	0.013	21.758	19.387	0.022	Reject H ₀
At most 5	8.420	12.517	0.219	8.420	12.517	0.219	Don't reject H ₀

emissions than the structure (DOLS) for Brazil. Whilst, for economic growth, both models (FMOLS and DOLS) have been results similarity. Another negative effect is specific to the way as is distributed the models, namely, (models (a), (a1) and (b), (b1), for these structures the energy sources take into account an unfavorable effect on economic growth. This result is similar to that found by Ref. [18,43], where the emission mitigation factors CO₂ emissions have a cost associated with sacrificing economic growth.

4.1. Robustness checks

The dimension of economic activity and the repercussions of electricity production and consequently of CO₂ emissions are captured by the cointegration models, which define possible interactions between each variable used by each model. A negative consequence is that the models may present specification bias or not be homoscedastic or may

Table 4
Long-run analysis – Economic growth.

Dependent variable = LGDP				
Explanatory	Model-(a)	FMOLS	Model-(a1)	DOLS
Variables	Coeff.	p-value	Coeff.	p-value
LPCO ₂	0.794 ^a	0.000	0.165 ^a	0.000
LHydro	−0.087 ^a	0.000	−0.476 ^a	0.000
LNatG	−0.005 ^a	0.000	−0.090 ^a	0.000
LRE	−0.341 ^a	0.000	−0.086 ^a	0.001
LOPen	0.329 ^a	0.000	0.405 ^a	0.000
Constant	3.834 ^a	0.000	−8.936 ^a	0.000
Diagnostic test				
	Test statistic	p-value		
LM (2)	32.361	0.642		
Heteroskedasticity	4.49 ^b	0.034		
Skewness	14.25 ^b	0.014		
Kurtosis	1.18	0.277		
ARCH	9.404 ^c	0.091		

Note: ^a, ^b and ^c indicate significance at 1%, 5%, and 10%, respectively; The Stata command “cointreg” was used to achieve the results for cointegration regression; LM: Lagrange multiplier test for autocorrelation; Heteroscedasticity is based on the regression of squared residuals on squared fitted values; Normality is based on a test of skewness and kurtosis of residuals.

Table 5
Long-run analysis – CO2 emissions.

Dependent variable = LPCO2				
Explanatory	Model-(a)	FMOLS	Model-(a1)	DOLS
Variables	Coeff.	p-value	Coeff.	p-value
LGDP	−1.568 ^a	0.000	0.358 [*]	0.370
LHydro	−5.433 ^a	0.000	0.621 ^b	0.016
LNatG	0.924 ^a	0.000	0.158 [*]	0.108
LRE	−0.238 ^a	0.000	0.451 ^a	0.000
LOPen	1.077 ^a	0.000	−0.670 ^a	0.000
Constant	−95.006 ^a	0.000	20.104 ^a	0.006
Diagnostic test				
	Test statistic	p-value		
LM (2)	32.361	0.642		
Heteroskedasticity	2.62	0.105		
Skewness	13.40 ^b	0.019		
Kurtosis	0.09	0.758		
Ramsey's RESET	2.25	0.100		

Note: ^a and ^b indicate significance at 1%, 5%, respectively; ^{*} denote not significant; the Stata command “cointreg” was used to achieve the results for cointegration regression; LM: Lagrange multiplier test for autocorrelation; Heteroscedasticity is based on the regression of squared residuals on squared fitted values; Normality is based on a test of skewness and kurtosis of residuals.

not have a standard normal distribution. To check for these possible modeling errors, standard diagnostic tests are performed to find out if the model is well specified, that is, that the regression assumptions are not compromised.

To first model (economic growth), we implement a Lagrange multiplier (LM) test for autocorrelation in the residuals of VAR models by Johansen [44]. We also implement the test of normality, serial correlation and autoregressive conditional heteroskedasticity (ARCH). To the second model (CO2 emissions) we add the Ramsey regression specification-error test for omitted variables. The null hypothesis of this test is, H0: the model has no omitted variables.

The results of the multiplier test of Lagrange (LM) reveal that there are no serial correlations in the model residues. The normality test concludes that the model residues have a normal distribution by kurtosis in the two results of the diagnostic tests (see Tables 4 and 5). The result for Ramsey's test proves that in the model there are no omitted variables, for the last test (see Table 5). Therefore, our findings are not motivated by discrepancies or sample selection and survive multiple specifications, allowing to observe the relationship with great accuracy. The diagnostic tests applied shown that results it is not misleading.

The results of the other auxiliary regressions can be found in table A3. In this stage, energy variables and commercial opening are dependent variables. The results show that the structure FMOLS that all series have significant coefficient values at level 1% significance with positive signs for the series: Natural gas and trade openness - model (c) and CO2 emissions, natural gas and trade openness - model (c1); CO2 emissions, hydropower, renewable energy - model (d) and CO2

emissions, hydropower, renewable energy, and trade openness (d1)); GDP, CO2 emissions, and hydropower - model (e) and GDP, natural gas and trade openness - model (e1)); GDP, CO2 emissions, hydropower, and renewable energy - model (f) and GDP, natural gas and trade openness - model (f1). The variables: trade openness - model (d1), CO2 emissions - model (e1) and (f1), natural gas - model (f1)) in the DOLS structure are not significant.

The next step was to apply Toda-Yamamoto to identify the directionality of variables. So, we set up a VAR model and we performed a non-Granger causality test using a Wald standard test. Table 6 shows the results of the causality test. A unidirectional causality is running from renewable energy to GDP and Hydropower, natural gas and trade liberalization to CO2 emissions. The feedback hypothesis is confirmed among all sources of energies and trade openness, and between GDP and natural gas. Also, the hypothesis of the growth is confirmed from renewable energy running to GDP, that is, the renewable energy accelerates the growth of GDP. Another observation is that trade openness increases the CO2 emission at the 10% significance level. These results align with FMOLS models that support the relationships long-run between variables. Also, the natural gas increases the CO2 emissions at the 5% significance level (see Fig. 4).

Given these results, we list some crucial points of this study. Firstly, the results have several implications in economic and environmental terms for Brazil. We highlight: (a) the main source of electricity in Brazil is particularly intensive in hydropower. However, as the economy develops, emissions related to energy consumption tend to increase with the growth of the economy; (b) the results of CO2 emissions (environmental degradation) imply that direct or indirect energy resources are associated with important development strategies and, therefore, should not be dissociated from plans to reduce environmental degradation; (c) the dimension continental that Brazil represents and its heterogeneity is one of the major challenges for policymakers to adopt a different strategy to improve people's quality of life and, at the same time, mitigate the risk of environmental deterioration; and (d), since higher levels of energy consumption is necessary for a high degree of economic

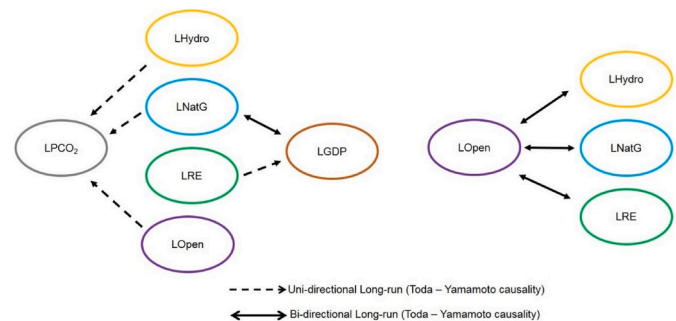


Fig. 4. Causality relationship flows.

Table 6
Granger causality Wald tests.

Wald test - (Chi-Square)						
Explanatory	Dependent Variables →					
Variables ↓	LPCO2	LGDP	LHydro	LNatG	LRE	LOPen
LPCO2		1.821 (0.402)	1.419 (0.492)	3.416 (0.181)	8.656 ^a (0.013)	1.798 (0.407)
LGDP	0.878 (0.644)		3.490 (0.175)	10.072 ^a (0.006)	3.856 (0.145)	4.122 (0.127)
LHydro	5.974 ^b (0.050)	2.511 (0.285)		0.648 (0.723)	22.401 ^a (0.000)	8.312 ^b (0.016)
LNatG	6.310 ^b (0.043)	6.000 ^b (0.050)	3.703 (0.157)		0.754 (0.686)	5.056 ^c (0.080)
LRE	2.715 (0.257)	7.383 ^b (0.025)	9.62 ^a (0.008)	4.643 ^c (0.098)		19.635 ^a (0.000)
LOPen	4.617 ^c (0.099)	3.606 (0.165)	6.971 ^b (0.031)	5.362 ^b (0.068)	80.076 ^a (0.000)	
All	25.955 ^a (0.004)	28.677 ^a (0.001)	28.029 ^a (0.002)	28.029 ^a (0.002)	118.29 ^a (0.000)	36.649 ^a (0.000)

Note: p-value is in parentheses; ^a, ^b and ^c indicate significance at 1%, 5%, and 10% respectively; the values of the Wald test are probabilities; The Stata command “vargranger” was used to achieve the results for Granger causality Wald tests.

growth and, consequently, induces the growth of CO₂ emissions, we can conclude that the sustainable development of electricity generation in Brazil is indispensable for long-term growth.

These clear implications can be explained by the fact that the Brazilian economy is eminently in transition and the increase in the average income of the population between 2002 and 2014 led to the expansion of consumption of industrialized goods. This mainly expanded the industrial sector concerning the primary sector (commodities), the latter, is Brazil's main export item. In this case, domestic consumption in this decade and a half was the main driver of the economic growth of Brazil. Although these results are consistent with existing studies, there are some uncertainties due to the driving forces behind recent changes at the political level concerning the Brazilian government's performance in the area of energy and the environment. Once that the investments in infrastructure that in previous governments were a priority, now those that are not paralyzed have been drastically reduced. And this can present a potential discrepancy considering the government of Brazil has moved in the direction of distancing public investment policies in areas considered to be priorities, this distancing can leave an important gap, whose the trend is to worsen the environmental and economic scenario.

An important way forward would be the incorporation and use of efficient technologies to leverage not only the level of economic production but also be effective in terms of cleaner production. But, as public policies (e.g., fiscal policies) imply a certain degree of market distortion due to unsustainable businesses supported by Brazil, this raises the possibility of worsening environmental and economic conditions. These effects represent some of the pros and cons of the analysis. Our results reveal still that a consequence of these discoveries and repercussions is that we cannot see any effect of the impact of current policies, due, above all, to the availability of data and recent events that requires more effective and efficient methodologies that in itself, justifies future research. Mainly because the withdrawal or reduction of public policies for structural economic investments and environmental protection are endogenous factors and may explain the conflicting results of the literature.

5. Conclusion and policy implications

This article shows how intermediate economies like Brazil's that are in different stages of development can improve the understanding of their energy potential to facilitate the design of policies that lead them to improve the use of available energy resources and, at the same time, mitigate the negative unintended consequences of this use. Specifically, we show the effects of the trajectories of electricity sources on the development process in Brazil and the impacts on environmental degradation, being the GDP, and CO₂ emissions the control variables. Therefore, the main contribution of the paper has been the characterization of the effects of electricity generation of various energetic sources, and trade openness over economic growth and CO₂ emissions in Brazil. We show that through the use of FMOLS and DOLS cointegration regression models that the long-term relationship has a strong consistency.

Although there is evidence that hydropower, natural gas, and renewable energy harm the GDP, it is not clear that this phenomenon is turn driven by energy conservation or growth policies. Concerning this finding, we offer a word of caution, once that suggests that although pollution emissions and trade openness benefits an increase in the GDP, the other variables suffer from it. Environmental results show that natural gas and trade openness have a positive impact on CO₂ emissions. Whilst, GDP, hydropower and renewable energy have negative impacts. On the other hand, the results of Toda-Yamamoto found bidirectional causality among all energy variables in towards trade openness and vice versa and from GDP for natural gas. That is, for both cases, the feedback hypothesis for Brazil is confirmed. Also, the unidirectional causality from renewable energy to GDP is confirmed at 5% significance level. This finding is particularly important because, for most studies on

economies in developing countries, the literature found results that support the presence of the conservation hypothesis, so something is changing, because, in this specific case, the opposite is confirmed, the hypothesis of growth with the use of renewable energies is found.

From a political and economic point of view, we can evaluate that the various paths to economic maturity are complex and the relationships that imply their development need to be an improvement. Thus, an ideal perspective would be to know how to manage energy resources in the face of climate benefits as opposed to the problems of environmental degradation. This suggests that environmental policies combined with sustainable resource management can impose better levels of environmental protection and have better conditions to widen the path of growth. Therefore, it demonstrates a great challenge for policymakers, which to more effectively and efficiently direct the movement of resources to more productive companies to offer concrete sustainable solutions. These actions can play a decisive role in mitigating large portions of Brazilian emissions. Thus, they are more investments in infrastructure focused on sustainable development are needed to support economic growth and the consequent reduction in emissions of CO₂ in Brazil. In this sense, the expectation of international financing through climate funds for developing countries can help overcome financial challenges for sustainable development in Brazil.

The political implications are diverse, because, energy production in Brazil is based on sources of hydropower and renewable energy. Indeed, the pressure of lack of investment in the energy sector (hydropower plants), whose, the government prioritize gave to private-sector plants until 2002 increased emissions related to the burning of fossil fuels; therefore, greenhouse gas (GHG) emissions in Brazil increased, while most developed countries have indicated that there will be a decline mainly due to investments in alternative energy sources; on the other hand, the public policies financial to several sectors were allocated in enterprises largely ineffective companies, as pointed out in the World Bank report that, at the federal level, about 4.5% of GDP was spent in 2016, including tax breaks, subsidized credits, and transfers to industries and various companies [1].

For these reasons, appropriate development strategies for the Brazilian economy, based on long-term sustainable development, are very important. This is part of a global trend in which the implementation of appropriate policies and the combination of financial resources and principally management capacity; in addition to increasing the use of energy from renewable sources can transform Brazil into a low carbon economy and energy efficiency and reduce the rate of pollution given the potential of available natural resources. We believe that it would be more persuasive to believe that open trade influences demand or energy for economic production. This hypothesis is confirmed by the results of all the methods used in the study. Therefore, the results reflect more causality than correlation, to provide a reasonable political recommendation for Brazil. Mainly to an understanding of the necessity of the generation of more hydropower plants, more renewable energy, and natural gas. This, added to the withdrawal and/or reduction of public policies for structural economic investments, social justice, and environmental protection justifies future research.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1

Overview of selected energy-growth nexus literature.

Countries	Period	Results	Methodology and author
Indonesia	1971–2009	Relationship between Energy ↔ GDP	ARDL/Engler-Granger Saboori & Sulaiman [32]
Singapore	1971–2009	Relationship between GDP → Energy	
Philippines	1971–2009	Relationship between Energy ↔ GDP	
Malaysia	1971–2009	Relationship between Energy ↔ GDP	
Thailand	1971–2009	Relationship between GDP → Energy	
Turkey	1960–2005	Relationship between Energy ≠ GDP	ARDL Ozturk & Acaravci [45]
Tanzania	1971–2006	Relationship between Energy → GDP	
ARDL/Toda-Yamamoto			Squalli [47]
Algeria	1980–2002	Relationship between GDP → Electricity	
Indonesia	1980–2002	Relationship between Electricity → GDP	
Iran	1980–2002	Relationship between GDP ↔ Electricity	
Iraq	1980–2002	Relationship between GDP → Electricity	
Kuwait	1980–2002	Relationship between GDP → Electricity	
Libya	1980–2002	Relationship between GDP → Electricity	
Nigeria	1980–2002	Relationship between Electricity → GDP	
Qatar	1980–2002	Relationship between GDP ↔ Electricity	
Saudi Arabia	1980–2002	Relationship between GDP ↔ Electricity	
UAE	1980–2002	Relationship between Electricity → GDP	
Venezuela	1980–2002	Relationship between Electricity → GDP	
Granger causality			
Argentina	1950–1990	Relationship between Energy ↔ GDP	
Brazil	1980–2007	Relationship between Energy ↔ GDP	
Macao	1999–2008	Relationship between GDP → Electricity	
Russia	1990–2007	Relationship between Energy ↔ GDP	
USA	1974–1989	Relationship between Energy ≠ GDP	
USA	1946–2000	Relationship between Energy → GDP	
South Africa	1980–2005	Relationship between GDP ≠ Coal	Granger causality Jinke et al. [54]
China	1980–2005	Relationship between GDP → Coal	
South Korea	1980–2005	Relationship between GDP ≠ Coal	
India	1980–2005	Relationship between GDP ≠ Coal	
Japan	1980–2005	Relationship between GDP → Coal	
Colombia	1970–1984	Relationship between GDP → Electricity	Granger causality Murray & Nan [55]
El Salvador	1980–2005	Relationship between GDP → Electricity	
Mexico	1980–2005	Relationship between GDP → Electricity	
Argentina	1950–1984	Relationship between Energy → GDP	Granger causality Nachane et al. [56]
Brazil	1950–1984	Relationship between Energy ↔ GDP	
Chile	1950–1984	Relationship between Energy → GDP	
Colombia	1950–1984	Relationship between Energy ↔ GDP	
Venezuela	1950–1984	Relationship between Energy ↔ GDP	
Brazil	1963–1993	Relationship between Energy → GDP	Granger causality Cheng [57]
Mexico	1963–1993	Relationship between Energy ≠ GDP	
Venezuela	1963–1993	Relationship between Energy ≠ GDP	
Johansen and Joselius			Chontanawat et al. [58]
Argentina	1971–2000	Relationship between Energy ↔ GDP	
Bolivia	1971–2000	Relationship between GDP → Energy	
Brazil	1971–2000	Relationship between Energy ↔ GDP	
Chile	1971–2000	Relationship between Energy → GDP	
Colombia	1971–2000	Relationship between Energy → GDP	
Ecuador	1971–2000	Relationship between Energy ≠ GDP	
Paraguay	1971–2000	Relationship between GDP → Energy	
Peru	1971–2000	Relationship between GDP → Energy	
Uruguay	1971–2000	Relationship between Energy → GDP	
Venezuela	1971–2000	Relationship between GDP → Energy	
Sims test			
USA	1947–1974	Relationship between GDP → Energy	
TAR			
Taiwan	1955–2003	Relationship between Energy → GDP	
VAR			
USA	1974–1990	Relationship between GDP → Energy	

(continued on next page)

Table A1 (continued)

Countries	Period	Results	Methodology and author
VAR Markov-Switching			
USA	1960–2005	Relationship between Energy ↔ GDP	Fallahi [61]
Panel/VECM			
Central America	1980–2004	Relationship between Energy→GDP	Apergis & Payne [62]
South America	1980–2005	Relationship between Energy→GDP	Apergis & Payne [63]
Sub-Sahara	1980–2008	Relationship between Energy ↔ GDP	Al-mulali & Sab [64]
ASEAN	1980–2006	Relationship between Electricity→GDP	Lean & Smyth [39]
BRICS	1992–2007	Relationship between Energy ↔ GDP	Pao & Tsai [65]
China	1982–2004	Relationship between Energy ↔ GDP	Chang [66]
France	1960–2000	Relationship between GDP→Energy	Ang [67]
MENA	1980–2009	Relationship between Energy ↔ GDP	Al-mulali [68]
OECD	1960–2005	Relationship between GDP→Energy	Costantini & Martini [69]
Asian countries	1971–2002	Relationship between Energy→GDP	Lee & Chang [70]
Turkey	1960–2006	Relationship between Energy≠GDP	Halicioglu [71]
			Panel/ARDL
5 European countries	1965–2009	Relationship between Energy ↔ GDP	Fuinhas & Marques [72]
Panel Granger			
15 European countries	1990–2011	Relationship between Energy→GDP	Ucan et al. [73]
OECD	1976–2009	Relationship between Crude oil ↔ GDP	Behmiri & Manso [74]
Latin America	1980–2012	Relationship between Crude oil→GDP	Behmiri & Manso [75]
G-7	1972–2002	Relationship between Energy→GDP	Narayan & Smyth [76]
OECD	1960–2001	Relationship between Energy ↔ GDP	Lee et al. [77]
OPEC	1971–2002	Relationship between Energy ↔ GDP	Mehrara [78]

Note: ARDL - Auto Regressive Distributed Lag; VAR - Vector Auto-Regressive; VECM - Vector Error Correction Model; TAR - Threshold Auto-Regressive model.

Table A2

Overview of selected energy-growth-environment nexus literature.

Countries	Period	Results	Methodology/author
Turkey	1960–2005	Relationship between Energy ↔ CO ₂ , GDP ↔ CO ₂	ARDL/VECM Halicioglu [71]
China	1995–2005	Relationship between GDP→CO ₂ , EKC inverted U	ARDL/EKC, VECM Jalil and Mahmud [79]
			ARDL
Denmark	1960–2005	Relationship between GDP→CO ₂	Acaravci and Ozturk [80]
Greece	1960–2005	Relationship between GDP→CO ₂	
Iceland	1960–2005	Relationship between GDP→CO ₂	
Italy	1960–2005	Relationship between GDP→CO ₂	
Portugal	1960–2005	Relationship between GDP→CO ₂	
Switzerland	1960–2005	Relationship between GDP→CO ₂	
Kuwait	1971–2017	Relationship between GDP→CO ₂ , CO ₂ →Energy, Energy ↔ CO ₂	ARDL/Granger causality Wasti and Zaidi [28]
India	1971–2006	Relationship between Energy→CO ₂ , GDP ↔ CO ₂	ARDL/Johansen-Juselius Ghosh [10]
China	1960–2007	Relationship between Energy→CO ₂	Toda-Yamamoto Zhang and Cheng [81]
Central America	1971–2004	Relationship between Energy→CO ₂ , GDP→CO ₂ , EKC inverted U	EKC/VECM Apergis and Payne [62]
ASEAN countries	1980–2006	Relationship between CO ₂ →Energy, EKC inverted U	EKC, VECM Lean and Smyth [39]
88 countries	1960–1990	Relationship Energy ↔ CO ₂	ECM Dinda and Coondoo [82]
BRIC	1971–2005	Relationship between Energy ↔ CO ₂ , CO ₂ →GDP	Pao and Tsai [83]
South Africa	1965–2006	Relationship between Energy→CO ₂ , CO ₂ →GDP	Engler-Granger Menyah and Rufael [84]
MENA	1980–2009	Relationship Oil ↔ CO ₂	Al-mulali [68]
Asian Pacific Countries	1971–2005	Relationship between Energy→CO ₂	Niu et al. [85]
USA	1960–2007	Relationship between Energy→CO ₂	Menyah and Rufael [86]
USA	1960–2004	Relationship between Energy→CO ₂	Soytas et al. [87]
Iran	1967–2007	Relationship between GDP→CO ₂	Lotfalipour et al. [88]
India and China	1967–2007	Relationship between Energy ↔ CO ₂	Chandran and Tang [89]
Bangladesh	1972–2006	Relationship between Energy→CO ₂	Johansen-Juselius Alam et al. [90]
China	1995–2007	Relationship between Energy ↔ CO ₂	Panel/VECM Wang et al. [91]
China	1977–2008	Relationship between Coal ↔ CO ₂	Bloch et al. [92]
China	1982–2004	Relationship between GDP ↔ CO ₂ , Relationship between Energy→CO ₂	Chang [66]
Brazil	1980–2007	Relationship between Energy ↔ CO ₂ , EKC inverted U	Pao and Tsai [49]
Russia	1990–2007	Relationship between GDP ↔ CO ₂ , CO ₂ →Energy	Pao et al. [51]

(continued on next page)

Table A2 (continued)

Countries	Period	Results	Methodology/author
Middle East	1990–2008	Relação entre Energia→CO ₂ , PIB→CO ₂	Painel P-VEC Ozcan [8]

Note: ARDL-Auto Regressive Distributed Lag; VAR-Vector Auto Regressive; VECM-Vector Error Correction Model/Mechanism; ECM-Error Correction Model/Mechanism; P-VEC -Panel Vector Error Correction.

Note: ^{sc} indicates lag order selected by the criterion; LR - sequentially modified LR test statistic (each test at 5% level); FPE - Final prediction error; AIC - Akaike information criterion; HQ - Hannan-Quinn information criterion; SC - Schwarz information criterion. NA - note available; The Software EViews11 was used to achieve the results for VAR lag order selection criteria with Lutkepohl's version of information criteria.

Note. ^a indicates that the hypotheses cointegration at the 0.05% level; ^b MacKinnon et al. (1999) p-value; Linear deterministic trend (restricted). Lag interval (in first difference) 1 to 3. The software EViews11 served to calculate the Johansen test.

Table A3

Long-run estimates auxiliaries.

Dependent	Explanatory	Model-(c) - FMOLS		Model-(c1) - DOLS	
Variable ↓	Variables ↓	coeff.	p-value	coeff.	p-value
LHydro	LGDP	−0.133 ^a	0.000	−0.286 ^a	0.000
	LPCO ₂	−0.133 ^a	0.000	0.165 ^a	0.000
	LNatG	0.219 ^a	0.000	0.196 ^a	0.000
	LRE	−0.071 ^a	0.000	−0.354 ^a	0.000
	LOpen	0.195 ^a	0.000	0.412 ^a	0.000
	Constant	−20.627 ^a	0.000	−23.339 ^a	0.000
Dependent	Explanatory	Model-(d) - FMOLS		Model-(d1) - DOLS	
Variable ↓	Variables ↓	coeff.	p-value	coeff.	p-value
LNatG	LGDP	−0.339 ^a	0.000	−1.872 ^a	0.000
	LPCO ₂	0.497 ^a	0.000	0.621 ^a	0.004
	LHydro	3.036 ^a	0.000	0.791 ^b	0.020
	LRE	0.619 ^a	0.000	0.801 ^a	0.000
	LOpen	−0.489 ^a	0.000	0.083 [*]	0.712
	Constant	61.094 ^a	0.000	32.658 ^a	0.001
Dependent	Explanatory	Model-(e) - FMOLS		Model-(e1) - DOLS	
Variable ↓	Variables ↓	coeff.	p-value	coeff.	p-value
LRE	LGDP	6.805 ^a	0.000	1.391 ^a	0.000
	LPCO ₂	1.301 ^a	0.000	0.050 [*]	0.345
	LHydro	12.165 ^a	0.000	−1.290 ^a	0.000
	LNatG	−1.390 ^a	0.000	0.521 ^a	0.000
	LOpen	−2.027 ^a	0.000	0.677 ^a	0.000
	Constant	144.218 ^a	0.000	−57.325 ^a	0.000
Dependent	Explanatory	Model-(f) - FMOLS		Model-(f1) - DOLS	
Variable ↓	Variables ↓	coeff.	p-value	coeff.	p-value
LOpen	LGDP	0.240 ^a	0.000	2.153 ^a	0.002
	LPCO ₂	0.109 ^a	0.000	−0.271 [*]	0.393
	LHydro	0.576 ^a	0.000	1.196 ^a	0.001
	LNatG	−0.108 ^a	0.000	0.089 [*]	0.649
	LRE	0.901 ^a	0.000	0.394 ^b	0.036
	Constant	47.406 ^a	0.000	28.189 ^a	0.016

Note: ^a and ^b indicate significance at 1%, 5%, respectively; ^{*} denote not significant; The Stata command “cointreg” was used to achieve the results for cointegration regression.

References

- [1] World Bank, A Agenda da Produtividade Emprego e Crescimento (Portuguese), 2018. Washington, D.C.
- [2] C.R.D.S. Filho, J.Z. Jr, C. Elvidge, “Brazil’s 2001 Energy Crisis Monitored from Space, vol. 1161, 2004, 2010.
- [3] R. Gremaud, A.P. Vasconcellos, M.A.S. Toneto, Economia Brasileira Contemporânea, eighth ed., São Paulo, Atlas, 2017, 2017.
- [4] E.L. La-Rovere, C. Grottera, W. Wills, Overcoming the financial barrier to a low emission development strategy in Brazil, *Int. Econ.* (2017) 1–8.
- [5] H.A. Domingos, A.M.M. Faria, J.A. Fuinhas, A.C. Marques, “Renewable energy and greenhouse gas emissions from the waste sectors of European Union member states : a panel data analysis, *Environ. Sci. Pollut. Res.* 24 (2017).
- [6] J. Kraft, A. Kraft, On the relationship between energy and GNP, *J. Energy Dev.* 3 (1978) 401–403.
- [7] A.B. Grossman, G.M. Krueger, Economic growth and the environment, *Q. J. Econ.* 110 (2) (1995) 353–377.
- [8] B. Ozcan, The nexus between carbon emissions, energy consumption and economic growth in Middle East countries: a panel data analysis, *Energy Pol.* 62 (2013) 1138–1147.
- [9] M. Hamit-Haggag, Greenhouse gas emissions, energy consumption and economic growth: a panel cointegration analysis from Canadian industrial sector perspective, *Energy Econ.* 34 (1) (2012) 358–364.
- [10] S. Ghosh, Examining carbon emissions economic growth nexus for India: a multivariate cointegration approach, *Energy Pol.* 38 (6) (2010) 3008–3014.
- [11] D. Flórez-orrego, J.A.M. Silva, S. De Oliveira, Renewable and non-renewable exergy cost and specific CO₂ emission of electricity generation: the Brazilian case, *Energy Convers. Manag.* 85 (2014) 619–629.
- [12] Aneel, Aplicações/capacidadeBrasil/Combustível (2018). Site: . [Online]. Available, www2.aneel.gov.br/2018, <https://www2.aneel.gov.br/aplicacoes/capacidadebrasil/Combustivel.cfm>.
- [13] T.L. Afonso, A.C. Marques, J.A. Fuinhas, “Interactions between electricity generation sources and economic activity in two Nord Pool systems : evidence from Estonia and Sweden, *Appl. Econ.* 6846 (2017) 1466–4283.

- [14] M.O. Appiah, Investigating the multivariate granger causality between energy consumption, economic growth and CO₂ emissions in Ghana, *Energy Pol.* 112 (October 2017) 198–208, 2018.
- [15] V. Moutinho, M. Robaina, Is the share of renewable energy sources determining the CO₂ kWh and income relation in electricity generation? *Renew. Sustain. Energy Rev.* 65 (2016) 902–914.
- [16] W.N. Cowan, T. Chang, R. Inglesi-Lotz, R. Gupta, The nexus of electricity consumption, economic growth and CO₂ emissions in the BRICS countries, *Energy Pol.* 66 (2014) 359–368.
- [17] M. Salahuddin, J. Gow, I. Ozturk, Is the long-run relationship between economic growth, electricity consumption, carbon dioxide emissions and financial development in Gulf Cooperation Council Countries robust? *Renew. Sustain. Energy Rev.* 51 (2015) 317–326.
- [18] S. Farhani, M. Shahbaz, What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO₂ emissions in MENA region? *Renew. Sustain. Energy Rev.* 40 (2014) 80–90.
- [19] M. Zhang, X. Liu, W. Wang, M. Zhou, Decomposition analysis of CO₂ emissions from electricity generation in China, *Energy Pol.* 52 (2013) 159–165.
- [20] H.A.D. Hdom, Examining carbon dioxide emissions, fossil & renewable electricity generation and economic growth: evidence from a panel of South American countries, *Renew. Energy* 139 (2019) 186–197.
- [21] H. Sadi, S. Prince, G. Uzuner, F. Victor, S. Asumadu, “Heliyon Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria : fresh insights from Maki Cointegration and causality tests, *Heliyon* 6 (2020), e03400. February.
- [22] O.B. Awodumi, A.O. Adewuyi, The role of non-renewable energy consumption in economic growth and carbon emission: evidence from oil producing economies in Africa, *Energy Strateg.* Rev. 27 (2020) 100434.
- [23] L. Charfeddine, M. Kahia, Impact of renewable energy consumption and financial development on CO₂ emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis, *Renew. Energy* 139 (2019) 198–213.
- [24] Y. Chen, Z. Wang, Z. Zhong, CO₂ emissions, economic growth, renewable and non-renewable energy production and foreign trade in China, *Renew. Energy* 131 (2019) 208–216.
- [25] A.A. Haug, M. Ucal, The role of trade and FDI for CO₂ emissions in Turkey: nonlinear relationships, *Energy Econ.* 81 (2019) 297–307.
- [26] S. Muhammad, X. Long, M. Salman, and L. Dauda, “Effect of urbanization and international trade on CO₂ emissions across 65 belt and road initiative countries,” *Energy*, vol. 196, 2020.
- [27] K.H. Nguyen, M. Kakinaka, Renewable energy consumption, carbon emissions, and development stages: some evidence from panel cointegration analysis, *Renew. Energy* 132 (2019) 1049–1057.
- [28] S.K.A. Wasti, S.W. Zaidi, An empirical investigation between CO₂ emission, energy consumption, trade liberalization and economic growth: a case of Kuwait, *J. Build. Eng.* 28 (November 2019) 101104. Mar. 2020.
- [29] E. Dogan, I. Ozturk, The influence of renewable and non-renewable energy consumption and real income on CO₂ emissions in the USA: evidence from structural break tests, *Environ. Sci. Pollut. Res.* 1 (2017).
- [30] D. Dickey, W.A. Fuller, Distribution of the estimates for autoregressive time series with a unit root, *J. th Am. Stat. Assoc.* 74 (366) (1979) 427–431.
- [31] P.C.B. Phillips, P. Perron, Testing for a unit root in time series regressions, *Biometrika* 75 (1998) 335–346.
- [32] B. Saboori, J. Sulaiman, CO₂ emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: a cointegration approach, *Energy* 55 (2013) 813–822.
- [33] M.A. Muhammad Tariq Iqbal Khan, Qamar AliQamar Ali, “The nexus between greenhouse gas emission, electricity production, renewable energy and agriculture in Pakistan,” *Renew. Energy* 118 (2018) 437–451.
- [34] B. Phillips, P. Hansen, “Statistical inference in instrumental variable regression with I(1) processes, *Rev. Econ. Stud.* 57 (1990) 99–125.
- [35] B. Inder, Estimating long-run relationships in economics: a comparison of different approaches, *J. Econom.* 57 (1993) 53–68.
- [36] M.W. Stock, J.H. Watson, A simple estimator of cointegration vectors in higher order integrated systems, *Econometrica* 61 (4) (1993) 783–820.
- [37] H. Mallick, M. Kumar, M. Sahoo, “Is crude oil price detrimental to domestic private investment for an emerging economy ? The role of public sector investment and financial sector development in an era of globalization, *Energy Econ.* 69 (2018) 307–324.
- [38] G. Akhmat, K. Zaman, T. Shukui, The Challenges of Reducing Greenhouse Gas Emissions and Air Pollution through Energy Sources: Evidence from a Panel of Developed Countries, 2014, pp. 7425–7435.
- [39] H.H. Lean, R. Smyth, CO₂ emissions, electricity consumption and output in ASEAN, *Appl. Energy* 87 (6) (2010) 1858–1864.
- [40] T. Toda, H.Y. Yamamoto, “Statistical inference in vector autoregressions with possibly integrated processes, *J. Econom.* 66 (1995) 225–250.
- [41] D. Adriana, Revisiting the relationship between unemployment rates and shadow economy. A Toda-Yamamoto approach for the case of Romania, *Procedia Econ. Financ.* 10 (2014) 227–236.
- [42] J.L. Esso, Long-Run relationship and causality between foreign direct investment and growth: evidence from ten African countries, *Int. J. Econ. Finance* 2 (2) (2010) 168–177.
- [43] M. Ben Jebli, S. Ben Youssef, I. Ozturk, Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries, *Ecol. Indic.* 60 (2016) 824–831.
- [44] S. Johansen, Likelihood-Based Inference in Cointegrated Vector Autoregressive Models, Oxford Oxford Univ. Press, 1995.
- [45] I. Ozturk, A. Acaravci, The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey, *Energy Econ.* 36 (2013) 262–267.
- [46] N.M. Odhiambo, Energy consumption and economic growth nexus in Tanzania: an ARDL bounds testing approach, *Energy Pol.* 37 (2) (2009) 617–622.
- [47] J. Squalli, Electricity consumption and economic growth: bounds and causality analyses of OPEC members, *Energy Econ.* 29 (6) (Nov. 2007) 1192–1205.
- [48] U. Soytas, R. Sari, Energy consumption and GDP: causality relationship in G-7 countries and emerging markets, *Energy Econ.* 25 (1) (2003) 33–37.
- [49] H.-T. Pao, C.-M. Tsai, Modeling and forecasting the CO₂ emissions, energy consumption, and economic growth in Brazil, *Energy* 36 (5) (2011) 2450–2458.
- [50] T.M. Lai, W.M. To, W.C. Lo, Y.S. Choy, K.H. Lam, “The causal relationship between electricity consumption and economic growth in a Gaming and Tourism Center: the case of Macao SAR, the People’s Republic of China, *Energy* 36 (2) (Feb. 2011) 1134–1142.
- [51] H.-T. Pao, H.-C. Yu, Y.-H. Yang, Modeling the CO₂ emissions, energy use, and economic growth in Russia, *Energy* 36 (8) (2011) 5094–5100.
- [52] E.S.H. Yu, J.C. Jin, Cointegration tests of energy consumption, income, and employment, *Resour. Energy* 14 (3) (Sep. 1992) 259–266.
- [53] B.S. Warr, R.U. Ayres, Evidence of causality between the quantity and quality of energy consumption and economic growth, *Energy* 35 (4) (2010) 1688–1693.
- [54] L. Jinke, S. Hualing, G. Dianming, Causality relationship between coal consumption and GDP: difference of major OECD and non-OECD countries, *Appl. Energy* 85 (6) (2008) 421–429.
- [55] G.D. Murray, D.A. Nan, A definition of the gross domestic product-electrification interrelationship, *J. Energy Dev.* 19 (1996) 275–283.
- [56] D.M. Nachane, R.M. Nadkarni, A.V. Karnik, “Co-Integration and causality testing of the energy-GDP relationship: a cross-country study, *Appl. Econ.* 20 (11) (1988) 1511–1531.
- [57] B.S. Cheng, Energy consumption and economic growth in Brazil, Mexico and Venezuela: a time series analysis, *Appl. Econ. Lett.* 4 (11) (1997) 671–674.
- [58] J. Chontanawat, L.C. Hunt, R. Pierse, Does energy consumption cause economic growth?: evidence from a systematic study of over 100 countries, *J. Pol. Model.* 30 (2) (2008) 209–220.
- [59] C.-C. Lee, C.-P. Chang, The impact of energy consumption on economic growth: evidence from linear and nonlinear models in Taiwan, *Energy* 32 (12) (2007) 2282–2294.
- [60] D.I. Stern, Energy and economic growth in the USA, *Energy Econ.* 15 (2) (Apr. 1993) 137–150.
- [61] F. Fallahi, Causal relationship between energy consumption (EC) and GDP: a Markov-switching (MS) causality, *Energy* 36 (7) (2011) 4165–4170.
- [62] N. Apergis, J.E. Payne, CO₂ emissions, energy usage, and output in Central America, *Energy Pol.* 37 (8) (Aug. 2009) 3282–3286.
- [63] N. Apergis, J.E. Payne, Energy consumption and growth in South America: evidence from a panel error correction model, *Energy Econ.* 32 (6) (2010) 1421–1426.
- [64] U. Al-mulali, C.N. Binti Che Sab, The impact of energy consumption and CO₂ emission on the economic growth and financial development in the Sub Saharan African countries, *Energy* 39 (1) (2012) 180–186.
- [65] H.T. Pao, C.M. Tsai, Multivariate Granger causality between CO₂ emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries, *Energy* 36 (1) (2011) 685–693.
- [66] C.-C. Chang, A multivariate causality test of carbon dioxide emissions, energy consumption and economic growth in China, *Appl. Energy* 87 (11) (2010) 3533–3537.
- [67] J.B. Ang, CO₂ emissions, energy consumption, and output in France, *Energy Pol.* 35 (2007) 4772–4778.
- [68] U. Al-mulali, Oil consumption, CO₂ emission and economic growth in MENA countries, *Energy* 36 (10) (2011) 6165–6171.
- [69] V. Costantini, C. Martini, The causality between energy consumption and economic growth: a multi-sectoral analysis using non-stationary cointegrated panel data, *Energy Econ.* 32 (3) (2010) 591–603.
- [70] C.-C. Lee, C.-P. Chang, Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data, *Resour. Energy Econ.* 30 (1) (2008) 50–65.
- [71] F. Halicioglu, An econometric study of CO₂ emissions, energy consumption, income and foreign trade in Turkey, *Energy Policy* 37 (2009) 1156–1164.
- [72] J.A. Fuinhas, A.C. Marques, Energy consumption and economic growth nexus in Portugal, Italy, Greece, Spain and Turkey: an ARDL bounds test approach (1965–2009), *Energy Econ.* 34 (2) (2012) 511–517.
- [73] O. Ucan, E. Aricioglu, F. Yucel, Energy consumption and economic growth nexus: evidence from developed countries in europe, *Int. J. Energy Econ. Pol.* 4 (3) (2014) 411–419.
- [74] N. Bashiri Behmiri, J.R. Pires Manso, Crude oil conservation policy hypothesis in OECD (organisation for economic cooperation and development) countries: a multivariate panel Granger causality test, *Energy* 43 (1) (2012) 253–260.
- [75] N. Bashiri Behmiri, J.R. Pires Manso, The linkage between crude oil consumption and economic growth in Latin America: the panel framework investigations for multiple regions, *Energy* 72 (2014) 233–241.
- [76] P.K. Narayan, R. Smyth, Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks, *Energy Econ.* 30 (5) (2008) 2331–2341.
- [77] C.C. Lee, C.P. Chang, P.F. Chen, Energy-income causality in OECD countries revisited: the key role of capital stock, *Energy Econ.* 30 (5) (2008) 2359–2373.

- [78] M. Mehrara, Energy consumption and economic growth: the case of oil exporting countries, *Energy Pol.* 35 (5) (May 2007) 2939–2945.
- [79] A. Jalil, S.F. Mahmud, Environment Kuznets curve for CO2 emissions: a cointegration analysis for China, *Energy Pol.* 37 (12) (2009) 5167–5172.
- [80] A. Acaravci, I. Ozturk, On the relationship between energy consumption, CO2 emissions and economic growth in Europe, *Energy* 35 (12) (Dec. 2010) 5412–5420.
- [81] X.-P. Zhang, X.-M. Cheng, Energy consumption, carbon emissions, and economic growth in China, *Ecol. Econ.* 68 (10) (2009) 2706–2712.
- [82] S. Dinda, D. Coondoo, Income and emission: a panel data-based cointegration analysis, *Ecol. Econ.* 57 (2006) 167–181.
- [83] H.-T. Pao, C.-M. Tsai, CO2 emissions, energy consumption and economic growth in BRIC countries, *Energy Pol.* 38 (12) (2010) 7850–7860.
- [84] K. Menyah, Y. Wolde-Rufael, Energy consumption, pollutant emissions and economic growth in South Africa, *Energy Econ.* 32 (6) (2010) 1374–1382.
- [85] S. Niu, Y. Ding, Y. Niu, Y. Li, G. Luo, Economic growth, energy conservation and emissions reduction: a comparative analysis based on panel data for 8 Asian-Pacific countries, *Energy Pol.* 39 (4) (2011) 2121–2131.
- [86] K. Menyah, Y. Wolde-Rufael, CO2 emissions, nuclear energy, renewable energy and economic growth in the US, *Energy Pol.* 38 (6) (2010) 2911–2915.
- [87] U. Soytas, R. Sari, B.T. Ewing, Energy consumption, income, and carbon emissions in the United States, *Ecol. Econ.* 62 (2007) 482–489.
- [88] M.R. Lotfalipour, M.A. Falahi, M. Ashena, Economic growth, CO2 emissions, and fossil fuels consumption in Iran, *Energy* 35 (12) (2010) 5115–5120.
- [89] V.G.R. Chandran Govindaraju, C.F. Tang, The dynamic links between CO2 emissions, economic growth and coal consumption in China and India, *Appl. Energy* 104 (2013) 310–318.
- [90] M. Jahangir Alam, I. Ara Begum, J. Buysse, G. Van Huylenbroeck, Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis, *Energy Pol.* 45 (2012) 217–225.
- [91] S.S. Wang, D.Q. Zhou, P. Zhou, Q.W. Wang, CO2 emissions, energy consumption and economic growth in China: a panel data analysis, *Energy Pol.* 39 (9) (2011) 4870–4875.
- [92] H. Bloch, S. Rafiq, R. Salim, Coal consumption, CO2 emission and economic growth in China: empirical evidence and policy responses, *Energy Econ.* 34 (2) (2012) 518–528.