Chapter 5
The Causality Between Energy Consumption, Urban Population, Carbon Dioxide Emissions, and Economic Growth

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Abstract This study evaluates the relationship between electric power consumption and urbanization comparing the econometric results of autoregressive distributed lag (ARDL) and vector autoregressive (VAR) for the period 1960–2015. Granger causality is also applied to the Portuguese economy. In this study, we use some hypotheses that describe the link between electric power consumption, urban population, carbon dioxide emissions, and economic growth. The motivation of this research focuses on the relationship between electric power consumption (energy consumption) and urban population, supported by the theoretical and empirical contributions of energy and urban economics. The empirical results show that electric power consumption presents a causality with economic growth, urban population, carbon dioxide emissions, and international trade. This research also proves that there is cointegration between all variables in the long run. This paper presents significant contributions to economic policy, showing that there exists an association between energy consumption and economic growth.

Keywords Energy consumption · Economic growth · Carbon dioxide emissions · Time series

JEL Classification Q43 · Q50

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5.1 Introduction

This chapter analyzes the cointegration between energy consumption, carbon dioxide emissions, economic growth, urban population, and trade. In this context, the arguments of regional and energy economics give support to this issue. Indeed, regional and urban economics show that the population tries to locate close to the urban system since there are more opportunities concerning employment. According to economic geography models (Krugman 1991; Fujita et al. 1999), we observe that the Center or the North is more attractive when compared with the peripheral or semi-peripheral areas. However, the urban population has higher energy consumption, when compared to small municipalities, that is, energy demand in large urban systems is higher. Recent studies by Ozturk and Acaravci (2011), Omri (2013), Shahbaz et al. (2013), Leitão (2015), and Bakirtas and Akpolat (2018) focused on this theme.

Moreover, the relationship of energy with international trade, international investment, as well as economic growth, has increased in the literature, showing the motivation of the researchers to evaluate this link. The scholars have required to correlate these variables using different econometric strategies. The present study uses time series for the case of the Portuguese economy capturing the results obtained between autoregressive distributed lag (ARDL), autoregressive vector (VAR), and Granger causality for the period 1960–2015.

Several studies such as Farabi et al. (2019), Hong et al. (2019), Saqib (2018), Sasana and Aminata (2019) demonstrate that energy consumption is needed to promote economic growth. However, growth encourages climate change and the greenhouse effect with the emission of gases. Consequently, international trade, via export growth strategy, uses excessive energy consumption, this practice is associated with economic growth, sometimes without considering sustainable development.

According to Portuguese publication of the General Direction of Energy and Geology (Direção Geral de Energia e Geologia, Energia em Números 2015: 4), the Portuguese economy presents an energy dependence to the outside world. In 2015, it registered 78.3%, increasing by about 5.9% compared to 2014. From data published by the same government institution, it can be observed that from 2010 onwards, energy dependence has declined concerning the years of the 1990s. From 1996 to 2009, it is always above 80%. Comparing Portugal with the EU-28 average, Portugal ranks 7th concerning energy dependency (Direção Geral de Energia e Geologia, Energia em Números 2015: 5). From this report, it is possible to observe the importance of the energy sector for Portuguese economic activity.

This study aims to contribute to the literature on this topic. At first, the empirical research relates to the long-run relationship between energy and economic growth. The urban population, carbon dioxide emissions, and international trade are also evaluated. This research is organized as follows. The literature review is presented in the next section. The methodology and the hypotheses are considered in section three. The empirical results appear in section four. The conclusions are described in the final of this study.

5.2 Literature Review

The demand energy has been widely discussed in the literature. In the last two decades, scientific articles on the use of fossil energy have increased, evidencing that it generates climate change and global warming. In this context, we present the most relevant literature review that evaluates the link between energy consumption, urban population, and economic growth. The correlation between energy consumption and carbon dioxide emissions (CO_2) and international trade is also considered. The introduction of the urban population is supported by theories of regional and urban economics associated with urban systems (Losch 1967; Christaller 1966; Fujita et al. 1999).

The empirical studies show that economic growth causes climate change and global warming. However, it should be noted that the urban population contributes to a higher energy demand, which in turn, the use of non-renewable energy encourages climate change. The empirical study of Bakirtas and Akpolat (2018) considers the causality between energy consumption, economic growth, and urbanization. Using the period 1971–2014, the authors applied a panel Granger causality to Colombia, India, Indonesia, Kenya, Malaysia, and Mexico, and the econometric results demonstrate that income per capita and urbanization present causality with energy consumption for all economies. Bakirtas and Akpolat (2018) also showed that there is a Granger causality between urbanization and income per capita in Kenya and Mexico. In this line, the empirical study of Khobai and Le Roux (2017) considered the link between energy consumption, CO_2 emissions, urbanization, and international trade in South Africa for the period 1971–2013, applying the vector error corrected model (VECM). The econometric results show that there is a bidirectional causality between energy consumption and economic growth. Khobai and Le Roux (2017) also demonstrate that there exists a unidirectional causality between energy consumption and all variables considered in their study.

The investigation realized by Zheng and Walsh (2019) considers the effects of urbanization, energy consumption, and international trade on economic growth. The authors applied panel data (fixed effects and GMM-System) considering 29 Chinese provinces for the period 2001–2012. The econometric results prove that urbanization encourages economic growth (Zheng and Walsh 2019: 159). Moreover, the study of Zheng and Walsh (2019) also shows that trade is negatively correlated with economic growth, and energy consumption does not endorse economic growth when the authors applied a dynamic panel estimator. In this context, Wang et al. (2018) studied the cointegration between urbanization, economic growth, and carbon dioxide emissions considering 170 countries with different development, for the period 1980–2011, and the empirical results demonstrate that there exist cointegration between variables used.

The case of Saudi Arabia was investigated by Alshehry and Belloumi (2015), considering a time series (unit root test, Johansen cointegration test, Granger causality test, and VECM), and the study proves that in the long run, the energy use, CO_2 emissions, economic growth, and the price of energy are cointegrated.

Urbanization and energy consumption applied to Pakistan were investigated by Shahbaz et al. (2017). The researchers consider the ARDL model and VECM Granger causality to examine the cointegration between the energy consumption, urban population, real income per capita, technology, and use of transportation (Shahbaz et al. 2017: 86). The empirical results show that there is cointegration between variables. When the authors utilize the ARDL model in the long run, it is possible to infer that the variables of the urban population, real income per capita, technology, and use of transportation present a positive effect on energy consumption.

The literature review also considers the correlation between energy consumption, economic growth, and carbon dioxide emissions. Usually, the empirical studies found a positive cointegration between energy consumption and economic growth. Besides, the intensive use of nonclean energy encourages an increase of carbon dioxide emissions, and consequently, climate change, and global warming (e.g., Mirza and Kanwal 2017; Farabi et al. 2019; Saqib 2018). In this context, Bildiric and Ozaksoy (2017) consider the cointegration between energy consumption and income per capita for the period 1980–2012 in African economies. These authors apply an autoregressive distributed lag model (ARDL) and Granger causality. The results show that there is a causality between energy consumption and growth for Botswana, Cameroon, Uganda, and Zambia.

The case for Taiwan, considering the input–output as an econometric strategy, was investigated by Hong et al. (2019). The study proves that energy consumption encourages economic growth. Besides, energy consumption increased after the financial crisis that according to the authors represents sustainable development. Farabi et al. (2019) investigated the correlation between energy consumption and economic growth applied to Indonesia and Malaysia. They concluded that there exists a cointegration between energy consumption and carbon dioxide emissions, energy consumption, and economic growth. The impact of China urbanization on economic growth and energy consumption was studied by Yang et al. (2017), for the period 2000–2010. The authors applied panel data (OLS, fixed effects, and random effects). The econometric results demonstrate that urbanization has a positive impact on energy consumption and economic growth. However, the empirical study of Jafari et al. (2012) presents a different position, i.e., not found a Granger causality between energy consumption and economic growth for the Indonesia case. Nevertheless, the study found a correlation between urban population and energy, showing that energy consumption is crucial in urban regions.

The influence of urbanization and industrialization on carbon dioxide emissions in China was considered by Liu and Bae (2018). The authors applied an ARDL methodology. In the long run, the variables of energy intensity, income per capita, industrialization, and urbanization present a positive impact on CO_2. Besides, the relationship between urbanization and energy demand in the Middle East was considered by Topcu and Girgin (2016), and the econometric results show that there is a causality between urbanization and energy demand.

Another area of research is the relationship between energy and international trade. The energy demand and the liberalization of markets show that there is cointegration between energy consumption and international trade. Economic globalization makes it possible to explain the growing demand for energy from countries that are not efficient in energy production. As a rule, empirical studies find a positive correlation between energy consumption and international trade, demonstrating that a country strategy based on export growth needs high levels of energy. On the other hand, environmental economists have shown that international trade stimulates carbon dioxide emissions, when the countries use nonclean energies, and consequently an increase in the excessive use of energy. Furthermore, the empirical study of Leitão (2015) considered the relationship between energy consumption and foreign direct investment, using panel data (fixed effects and GMM-System), the econometric results show that the international trade presents a positive impact on energy consumption.

The link between economic growth, energy consumption, financial development, international trade, and carbon dioxide emissions in Indonesia was examined by Shahbaz et al. (2013). Using the ARDL model, VECM, and Granger causality, the authors prove that there is a positive association between openness trade and carbon dioxide emissions and energy consumption. In this line, the empirical model of Ozturk and Acaravci (2011) considered 11 MENA countries and the ARDL model as the econometric strategy. The econometric results presented by Ozturk and Acaravci (2011) demonstrate that there is no cointegration between energy consumption and economic growth when the authors examine Iran, Morocco, and Syria. However, this empirical study proves that there exist cointegration and causality between energy consumption and economic growth to Egypt, Israel, Oman, and Saudi Arabia (Ozturk and Acaravci 2011: 2890–2891).

The effects of international trade, energy consumption, and economic growth on CO_2 emissions were studied by Akin (2014). The study used as an econometric strategy a panel cointegration (FMOLS and DOLS), and the econometric results demonstrate that international trade presents a positive effect on energy consumption and CO_2 emissions.

The MENA countries for the period 1990–2011, using dynamic panel data, were considered by Omri (2013). The empirical study proves that international trade has a positive impact on energy consumption in Algeria, Egypt, Kuwait, Saudi Arabia, Syria, and United Arab Emirates (Omri 2013: 662).

The relationship between globalization and energy and growth was investigated by Marques et al. (2017). Considering the ARDL model, the results demonstrate that there is cointegration between globalization, energy consumption, and growth.

Shahbaz et al. (2018) studied the correlation between energy consumption and foreign capital inflows applied to Pakistan. The scholars use an ARDL model and Granger causality for the period 1972–2014. The econometric results show that there exists bidirectional causality between exports, economic growth, and energy consumption.

5.3 Methodology and Hypotheses

This article considers the methodology of cointegration (autoregressive and distributed lag [ARDL]) developed by Perasan et al. (2001), and the development proposed by Kripfganz and Schneider (2016, 2018) to estimate the long-run relationship between electric power consumption, urban population, carbon dioxide emissions, income per capita, and total exports for the period 1960–2015. However, in this research, we also consider the unit root test, vector autoregressive (VAR), and Granger causality to evaluate the correlation between the variables used in this study. The unit root test permits to observe if there exists stationarity between the variables applied in this empirical study. The stationarity properties of the variables of energy consumption, carbon dioxide emissions, income per capita, urban population, and exports were tested by the method of Phillips and Perron (1988). The methodologies of Johansen and Juselius (1990) and Johansen (1988, 1991, 1995) were considered to study the cointegration. Before we estimate the VAR model, we need to consider the test of lag order selection criteria. Lagrange multiplier test was also considering to detect the stability of VAR model. According to the literature, the VAR model is stable if we do not have autocorrelation.

Based on the literature review, we formulate the following hypotheses:

øH_1: Energy consumption causes climate change

The literature review supports that electric power consumption encourages climate change and global warming.

Energy—the variable represents the electric power consumption per capita (kWh per capita) by World Bank and www.iea.org.

CO_2—represents the carbon dioxide emissions in Kt from World Bank.

The empirical studies of Farabi et al. (2019), Hong et al. (2019), Khobai and Le Roux (2017), Alshehry and Belloumi (2015), and Leitão (2015) demonstrate that CO_2 emissions present a positive effect on energy consumption. In this study, climate change is measured by CO_2 emissions.

H_2: There is a bidirectional causality between energy consumption and economic growth

Y—the variable denotes income per capita (constant 2010 US$) from the World Bank.

The previous studies (Sasana and Aminata 2019; Bildiric and Ozaksoy 2017; Magazzino 2015; Naina et al. 2017; Omri 2013) found a positive effect of energy consumption on economic growth. Indeed, economic growth depends on energy efficiency. Therefore, the use of non-renewable energy promotes climate change and global warming problems.

H_3: There is a positive relationship between urban population and energy consumption

In the urban system, energy consumption is higher when compared to small rural clusters.

The empirical studies of Zheng and Walsh (2019), Wang et al. (2018), Shahbaz et al. (2017), Yang et al. (2017), Liu and Bae (2018), Bakirtas and Akpolat (2018), Khobai and Le Roux (2017), and Jafari et al. (2012) give support to our hypothesis.
UrbanPop—signifies urban population, i.e., the population living in urban areas from the World Bank. This variable aims to measure the urbanization effects on energy consumption.
H_4: International trade is directly correlated with energy consumption
A strategy to promote export growth is associated with excessive use of energy demand.

The studies of Shahbaz et al. (2013), Akin (2014), and Leitão (2015) found a positive effect between international trade and energy consumption.

Exports—represents exports of goods and services (constant 2010 US$) source World Bank.

Considering the empirical studies of Ozturk and Acaravci (2011), Shahbaz et al. (2011), Shahbaz et al. (2013), Shahbaz et al. (2015), Elfaki et al. (2018), and Sriyana (2019), the ARDL model assumes the following expression:

$$\begin{aligned}\Delta LogEnergy = {} & \alpha_0 + \alpha_1 LogEnergy_{t-1} + \alpha_2 LogCO_{2t-1} + \alpha_3 LogY_{t-1} \\ & + \alpha_4 \Delta LogUrbanPop_{t-1} + \alpha_5 \Delta LogExports_{t-1} \\ & + \Sigma_{t=1}^{n} \alpha_1 \Delta LogEnergy_{t-1} + \Sigma_{t=0}^{n} \alpha_2 \Delta LogCO_{2t-1} \\ & + \Sigma_{t=0}^{n} \alpha_3 \Delta LogY_{t-1} + \Sigma_{t=0}^{n} \alpha_4 \Delta LogUrbanPop_{t-1} \\ & + \Sigma_{t=0}^{n} \alpha_5 \Delta LogExports_{t-1} + \gamma ECM_{t-1} + e \end{aligned} \tag{5.1}$$

The energy consumption is the dependent variable, and the independent variables considered are the carbon dioxide emissions (CO_2), income per capita (Y), urban population (*UrbanPop*), and total exports (*Exports*).

In Eq. 5.1, all variables are expressed in logarithm form. Δ represents the change in operator; ECM_{t-1} considers the error correction term; γ represents the adjustment of a short and long run.

Considering the contributions of Perasan et al. (2001), Shahbaz et al. (2015), Matthew et al. (2018), and Sriyana (2019), we need to consider two conditions with ARDL methodology:

H_0: $\alpha_0 = \alpha = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5$, represents no relationship in the long run.
H_1: $\alpha_0 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5$, represents the relationship in the long run.

To test cointegration and stationarity in the long run, we use the ARDL bounds test (Pesaran and Shin 1999; Pesaran et al. 2001). Therefore, the evaluate long-run cointegration used to the STATA software was determinate by the suggestion proposed by Kripfganz and Schneider (2016, 2018). Following the contributions of Edoja et al. (2016), Ullah et al. (2018) vector autoregressive (VAR) assumes the form:

$$Y_t = \alpha + A_1 Y_{t-1} + \ldots A_p Y_{t-p} + e_t \tag{5.2}$$

Y—represents all variables used in this study, i.e., energy consumption, carbon dioxide emissions, income per capita, urban population, and exports.

5.4 Empirical Results

The descriptive statistics and the correlation between the variables used in this research are presented in Tables 5.1 and 5.2. The variables of the urban population (*LogUrbanPop*), carbon dioxide emissions ($LogCO_2$), and income per capita (*LogY*) present higher values when we compare with energy consumption (*LogEnergy*) and exports (*LogExports*). The statistics of Skewness and Kurtosis are essential to evaluate the distribution of the frequencies of the variables compared to the normal distribution (Gaussian). The variables used in this study present negative values for

Table 5.1 Descriptive statistics

	LogEnergy	$LogCO_2$	*LogY*	*LogUrbanPop*	*LogExports*
Mean	3.263	4.481	4.125	6.658	0.726
Median	3.313	4.498	4.145	6.667	0.824
Maximum	3.695	4.824	4.358	6.815	1.070
Minimum	2.505	3.915	3.653	6.490	0.300
Std. dev.	0.365	0.272	0.209	0.105	0.250
Skewness	−0.516	−0.528	−0.727	−0.058	−0.220
Kurtosis	2.058	2.044	2.460	1.662	1.370
Jarque-Bera	4.470	4.649	5.525	4.130	6.528
Probability	0.106	0.097	0.063	0.126	0.038
Sum	179.466	246.5070	226.9201	366.2112	39.9736
Sum sq. dev.	7.2146	3.995	2.3706	0.598	3.395
Observations	55	55	55	55	55

Source Own composition based on World Bank Development Indicators

Table 5.2 Correlation between variables

Variables	*LogEnergy*	$LogCO_2$	*LogY*	*LogUrbanPop*	*LogExports*
LogEnergy	1.000				
$LogCO_2$	0.975	1.000			
LogY	0.966	0.997	1.000		
LogUrbanPop	0.914	0.977	0.986	1.000	
LogExports	0.060	0.250	0.295	0.418	1.000

Note Observations = 55
Source Own composition based on World Bank Development Indicators

Skewness, demonstrating that the distribution is asymmetric. This type of distribution is designated in the literature by negative or at the left asymmetry.

Regarding the Kurtosis statistics, it evaluates the "flattening" of the curve considering the Gaussian distribution. According to Table 5.1, it is possible to observe that the values are all positive, which is denominated by Kurtosis of the leptokurtic type. Moreover, all explanatory variables show a positive correlation with the dependent variable (energy consumption, see Table 5.2).

Table 5.3 presents the unit roots test for each variable used in this research, considering the Phillips–Perron (1988). According to the literature such as Hamilton (1994), Phillips–Perron's unit root test allows correcting serial correlation and heteroskedasticity by the Newey–West procedure (1987), using lags in the variations of the first differences. The Phillips–Perron test (1988) relies on two statisticians Z (rho)-Phillips–Perron t-test statistic and Z (t)-Phillips–Perron p statistic test. According to Hamilton (1994), the reading of these two statistics can be analyzed in the same way as the Dickey–Fuller test (1979). Thus, the null hypothesis considers that the variable in the analysis has a unit root, and alternatively, the variable will be stationary. In other words, the Phillips–Perron methodology tests whether the null hypothesis is integrated into order 1. The hypothesis rejection demonstrates that the time series are integrated into order n. The variables are stationary, considering the results obtained for the Z (rho) and Z (t) statistics.

Table 5.4 shows the lag selection considering LL—lag order selected by criterion, LR—Sequential modified, FPE—final prediction error, AIC—Akaike information criterion, SBIC—Schwarz information criterion, and HQ—Hannan–Quinn information criterion. Following the literature review such as Hamilton (1994), Lutkepohl (1993), Tsay (1984), and the results obtained in Table 5.4, we select the optimal lag to estimate the VAR model.

The autoregressive and distributed lag model (ARDL) is presented in Table 5.5. All variables were considered in the regression. The adjustment coefficient or error correction coefficient [ADJLogEnergy (−1)] demonstrates that there is a long relationship between variables. The lagged variable of energy is statistically significant at 1% level with a negative sign. In the long run, we can infer that energy consumption tends to decrease. However, in the short run, the energy consumption (*LogEnergyLD*) presents a positive sign showing that in the short run, it is essential for economic growth. In the long term, the coefficients of income per capita (*LogY*) and urban population (*LogUrbanPop*) present a positive effect on energy consumption. These variables are statistically significant at 1% level. Additionally, these results are according to the empirical studies of Bildiric and Ozaksoy (2017), Bakirtas et al. (2018), and by Alshehry and Belloumi (2015). It is also possible to infer a relationship between economic growth and energy use, which shows that energy demand is essential for the development of the economic activity. Besides, urban systems need more energy, i.e., they consume more energy than small population clusters like villages or small cities. Hence, we observe that there is a positive correlation. The econometric model also demonstrates that CO_2 emissions have a positive impact on energy consumption (*LogEnergy*), showing that there exists a relationship between energy consumption and climate change. The coefficient is statistically significant at 1% level. Bildiric

Table 5.3 Unit root rest: Phillips–Perron

Phillips–Peron unit root test	Interpolated Dickey–Fuller			
Variables	Test statistic	1% Critical value	5% Critical value	10% Critical value
LogEnergy				
Z (rho)	−14.506	−18.954	−13.324	−10.718
Z (t)	−7.022	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogCO_2				
Z (rho)	−18.213	−18.954	−13.324	−10.718
Z (*t*)	−9.183	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogY				
Z (rho)	−18.627	−18.954	−13.324	−10.718
Z (*t*)	−9.985	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogUrbanPop				
Z (rho)	−20.762	−18.954	−13.324	−10.718
Z (*t*)	−11.169	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
LogExports				
Z (rho)	−18.674	−18.954	−13.324	−10.718
Z (*t*)	−9.084	−3.576	−2.928	−2.599
MacKinnon approximate *p*-value for *Z* (*t*)	0.0000			
Observations	53			
New–West lags	3			

Note Rejection at 5% level
Source Own composition based on World Bank Development Indicators

Table 5.4 Lag order selection criteria

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	404.938		2.8e−14	−17.0186	−16.9446	−16.8218
1	752.75	695.62	3.0e−20	−30.7553	30.3109	−29.5744[a]
2	800.056	94.612	1.2e−20[a]	−31.7045	−30.8898[a]	−29.5395
3	825.353	50.593	1.3e−20	−31.7172	−30.5321	−28.568
4	856.775	62.843[a]	1.2e−20	−31.9904[a]	−30.435	−27.8571

Note [a]Represents the optimal lag
Source Own composition based on World Bank Development Indicators

and Ozaksoy (2017), Bakirtas and Akpolat (2018) also found a positive correlation between CO_2 emissions and energy consumption. The coefficient of exports (*LogExports*) presents a positive impact on energy consumption. The variable is statistically significant at 1% level. Leitão (2015), Akin (2014), and Shahbaz et al. (2013) give support to our results. The long-term cointegration between variables will be considered in the next step. Using the ARDL bounds test (Pesaran and Shin 1999) and the Kripfganz and Schneider methodology 2016, 2018), the statistics are presented in Table 5.6. The results demonstrate that there exists a long-run relationship (Fig. 5.1).

Based on the arguments of Johansen and Juselius (1990), and Johansen (1991, 1995, 1988), we apply the test of cointegration for the variables energy consumption (*LogEnergy*), carbon dioxide emissions ($LogCO_2$), income per capita (*LogY*), urbanization (*LogUrbanPop*), and exports (*Log exports*). In Table 5.7, the Trace test shows that there is two cointegration between the variables at the 5% level. The Maximum Eigenvalue test in Table 5.8 indicates that there exists one cointegration.

Table 5.9 presents the diagnostic of the VAR model, considering as H0: no serial correlation, the Lagrange multiplier test demonstrates that VAR is stable in lag 2.

Table 5.10 reports the results of Granger causality. There is bidirectional causality between energy consumption (*LogEnergy*) and income per capita (*LogY*). This result confirms again that energy demand is essential to obtain economic growth. We also observe that there is bidirectional causality between energy consumption (*LogEnergy*) and urban population (*LogUrbanPop*); and the variable of carbon dioxide emissions ($LogCO_2$) and urban population; and income per capita (*LogY*) and urban population (*LogUrbanPop*) (Fig. 5.2).

According to these results, it is possible to infer that there is a positive correlation between energy consumption and urban population, i.e., energy demand increases in urban agglomerations. The results also indicate that large urban systems are more polluting as there is a positive relationship between carbon dioxide emissions and the urban population. On the other hand, the population tends to be concentrated in urban clusters since there is more distribution of income per capita. This result is supported by the arguments of regional and urban economics (e.g., Christaller 1966; Krugman 1991). The empirical studies of Bakirtas and Akpolat (2018), Khobai and Le Roux (2017), Alshehry and Belloumi (2015) also found similar results.

Table 5.5 Energy consumption and Portuguese urban population with Autoregressive and Distributed Lag (ARDL)

Variables	Coef.
ADJ *LogEnergy* (−1)	−0.8952*** (0.001)
Long Run (LR)	
$LogCO_2$	0.2776*** (0.000)
LogY	0.8101*** (0.000)
LogUrbanPop	1.3596*** (0.000)
LogExports	0.1124*** (0.000)
Short Run (SR)	
LogEnergyLD	0.29983* (0.099)
L2D	0.2706 (0.149)
L3D	0.0917 (0.564)
$LogCO_2D1$	−0.030 (0.617)
LogYD1	−0.2002 (0.309)
LD	−0.4641** (0.025)
L2D	−0.3597* (0.050)
L3D	−0.2548* (0.092)
LogUrbanPopD1	−1.8219 (0.179)
LD	1.6506 (0.267)
L2D	0.1014 (0.118)
L3D	0.1061* (0.062)
LogExportsD1	−0.0619* (0.065)
LD	−0.0628** (0.014)

(continued)

Table 5.5 (continued)

Variables	Coef.
L2D	−0.0239 (0.264)
C	−9.3403*** (0.002)
Adj. R^2	0.843

Note Statistically significant at 1% (***), 5% (**), and 10% (*); LD—represents Lag
Source Own composition based on World Bank Development Indicators

Table 5.6 Energy consumption and Portuguese urban population with ARDL: bounds test

Pesaran, Shin and Smith (2001) bounds test								
F = 7.039 t = −4.657 Case 3								
Sample (4 variables, 47 observations, 16 short-run coefficients)								
Kripfganz and Schneider (2018) critical values and approximate *p*-values								
	10%		5%		1%		*p*-value	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	2.483	3.928	3.025	4.683	4.321	6.477	0.000	0.006
T	−2.416	−3.522	−2.788	−3.957	−3.543	−4.837	0.001	0.014

Source Own composition based on World Bank Development Indicators

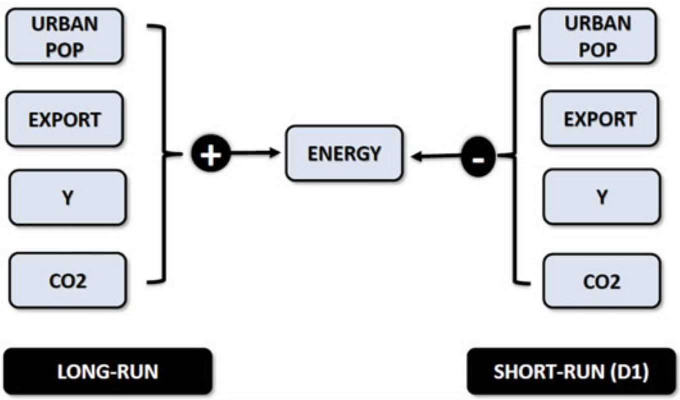

Fig. 5.1 (ARDL) scheme

There is a unidirectional causality between CO_2 emissions and energy consumption (*LogEnergy*), energy consumption, and exports (*LogExports*). The same is valid between $LogCO_2$ (carbon dioxide emissions) and *LogY* (income per capita).

Table 5.7 Energy consumption and Portuguese urban population with Unrestricted Cointegration Rank Test (Trace)

Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None	0.532170	91.99467*	69.81889	0.0003
At most 1	0.399609	51.73317*	47.85613	0.0207
At most 2	0.312816	24.69397	29.79707	0.1727
At most 3	0.076392	4.810845	15.49471	0.8286

* Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) *p*-values
Source Own composition based on World Bank Development Indicators

Table 5.8 Energy consumption and Portuguese urban population with Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical value	Prob.**
None*	0.532170	40.26150*	33.87687	0.0076
At most 1	0.399609	27.03920	27.58434	0.0586
At most 2	0.312816	19.88312	21.13162	0.0740
At most 3	0.076392	4.211768	14.26460	0.8364
At most 4	0.011240	0.599077	3.841466	0.4389

* Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) *p*-values
Source Own composition based on World Bank Development Indicators

Table 5.9 Energy consumption and Portuguese urban population: VAR Diagnostic

Lag		Chi2	Prob > Chi2
2		26.2403	0.39486

Source Own composition based on World Bank Development Indicators

The results show that international trade is associated with excessive use of energy, demonstrating that Portugal should use renewable energy to reduce polluting gases. On the other hand, the results also explain that there is a correlation between carbon dioxide emissions and economic growth. Once again, economic growth seems to simulate climate change.

Table 5.10 Energy consumption and Portuguese urban population with Granger causality

Null hypothesis	Chi 2	Df	Prob > Chi 2
LogEnergy does not Granger Cause $LogCO_2$	2.9501	2	0.229
$LogCO_2$ does not Granger Cause *LogEnergy*	11.303	2	0.004
LogEnergy does not Granger Cause *LogY*	16.76	2	0.000
LogY does not Granger Cause *LogEnergy*	93.159	2	0.000
LogEnergy does not Granger Cause *LogUrbanPop*	314.61	2	0.000
LogUrbanPop does not Granger Cause *LogEnergy*	971.55	2	0.000
LogEnergy does not Granger Cause *LogExports*	7.732	2	0.021
LogExports does not Granger Cause *LogEnergy*	0.2039	2	0.903
$LogCO_2$ does not Granger Cause *LogY*	7.7432	2	0.021
LogY does not Granger Cause $LogCO_2$	0.02184	2	0.989
$LogCO_2$ does not Granger Cause *LogUrbanPop*	180.58	2	0.000
LogUrbanPop does not Granger Cause $LogCO_2$	28.48	2	0.000
$LogCO_2$ does not Granger Cause *LogExports*	0.22605	2	0.893
LogExports does not Granger Cause $LogCO_2$	1.1028	2	0.576
LogY does not Granger Cause *LogUrbanPop*	355.5	2	0.000
LogUrbanPop does not Granger Cause *LogY*	104.38	2	0.000
LogY does not Granger Cause *LogExports*	6.8495	2	0.033
LogExports does not Granger Cause *LogY*	0.0726	2	0.964
LogUrbanPop does not Granger Cause *LogExports*	92.098	2	0.000
LogExports does not Granger Cause *LogUrbanPop*	0.2905	2	0.865

Source Own composition based on World Bank Development Indicators

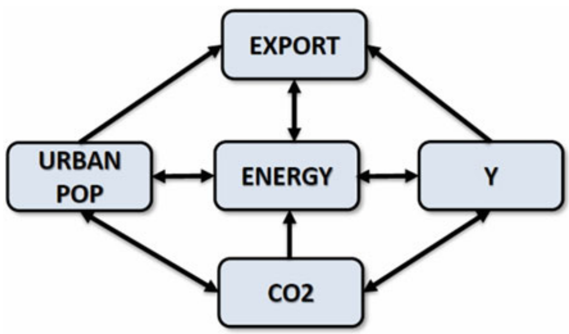

Fig. 5.2 Causality scheme

5.5 Conclusions

This study evaluates the long-term relationship between energy consumption, urban population, economic growth, climate change, and international trade (via export growth), comparing the econometric results between the ARDL model, VAR, and Granger causality. The econometric models that we present demonstrate the relevance of the link between energy consumption and the urban system (urbanization). It is our primary objective in this section to compare the results that we have found with other studies in the same area of knowledge.

Considering the results obtained by ARDL, it is possible to observe that there is a long-run cointegration between the variables used in this study. An analysis in more detail allows indicating that the long-run electric power consumption is adjusted, with a decrease in energy use. The long-run results also show that estimates of the urban population, economic growth, exports, and carbon dioxide emissions have a positive impact on energy consumption. The relationship between growth and energy is positive since the economic activity requires high energy consumption, demonstrating that to occur, economic growth energy is fundamental. This result is according to empirical studies of Shahbaz et al. (2018), Bildiric and Ozaksoy (2017), and Omri (2013).

Large urban systems have higher levels of energy consumption when compared to small cities, as analyzed by Shahbaz et al. (2017), Yang et al. (2017), and Liu and Bae (2018).

Regarding the relationship between carbon dioxide emissions and energy consumption, the positive association shows that excessive use of energy and especially electric power consumption cause climate change and global warming. The empirical studies of Alshehry and Belloumi (2015), and Khobai and Le Roux (2017) support our results.

Considering the data obtained by the Granger causality, we can affirm that these are according to the literature since there is bidirectional causality between the energy and the economic growth and the urban population.

As we mentioned, the econometric results demonstrate that energy consumption decreases in the long term. In terms of recommendations by the economic policy, we think that economic policymakers should consider a strategy to promote the use of renewable energies. The Portuguese state and the European Union should continue to finance sectors of economic activity that use renewable energies since these, in a long-term perspective, become more efficiencies.

Besides, our empirical results demonstrate that exports need excessive use of energy consumption. In this context, the Portuguese state should finance the strategic sectors of the economy based on the use of renewable energies, will be betting on the differentiation of products and factors of innovation and competitiveness, thus developing competitive clusters medium and long term.

Appendix

See Table 5.11.

Table 5.11 Energy consumption and Portuguese urban population growth with VAR model

Variables	*LogEnergy*	$LogCO_2$	*LogY*	*LogUrbanPop*	*LogExports*
LogEnergy (−1)	0.9897*** (0.000)	−0.0147 (0.739)	0.3247 (0.144)	0.2852*** (0.004)	0.0028 (0.998)
LogEnergy (−2)	0.1553 (0.373)	0.3645 (0.376)	0.0067 (0.932)	0.2166** (0.019)	−0.0772 (0.938)
$LogCO_2$ (−1)	0.0011 (0.986)	0.7955*** (0.000)	−0.0107 (0.893)	−0.0512 (0.143)	−0.3829 (0.307)
$LogCO_2$ (−2)	0.0567 (0.399)	0.1554 (0.329)	−0.6420 (0.893)	−0.0463 (0.19)	0.3862 (0.314)
LogY (−1)	0.1259 (0.353)	0.7472** (0.020	0.9218**** (0.000)	0.4195*** (0.000)	0.0871 (0.910)
LogY (−2)	0.3511*** (0.004)	−0.8097*** (0.005)	−0.3825*** (0.009)	0.0435 (0.506)	−0.1564 (0.824)
LogUrbanPop (−1)	−0.4489*** (0.000)	−0.8424*** (0.000)	0.6420*** (0.000)	0.1636*** (0.000)	0.0690 (0.830)
LogUrbanPop (−2)	0.0958* (0.085)	0.2143 (0.103)	0.2045*** (0.002)	−0.0795*** (0.007)	−0.1200 (0.705)
LogExports(−1)	0.0705*** (0.006)	−0.0285 (0.636)	−0.0759*** (0.012)	−0.0406*** (0.003)	0.7439*** (0.000)
LogExports(−2)	0.0559** (0.024)	0.0228 (0.696)	0.0531* (0.071)	−0.0248* (0.059)	0.0949 (0.501)
C	2.5787*** (0.000)	3.9686*** (0.000)	3.6984 (0.000)	6.5067*** (0.000)	0.9595 (0.8603)
Adj. R^2	0.99	0.99	0.99	0.99	0.96
P > Chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Log likelihood					766.9181
AIC					−27.91836
HQIC					27.12225
SBIC					−25.83501

Statistically significant at 1% (***), 5% (**), and 10% (*)
Source Own composition based on World Bank Development Indicators

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