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Renewable and non-renewable energy consumption, environmental degradation and economic growth in Tunisia

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Abstract The aim of this document is to investigate the dynamic relationship between economic growth, renewable energy consumption, energy consumption and CO_2 emissions in Tunisia over the period 1990–2015. Unit root tests and co-integration test was used in order to detect the order of stationary and to test the existence long run links between the used variables. We apply the Granger causality test and VECM model to discover the short and long run links between the variables. Results have shown a bidirectional causal relationship between energy use and CO_2 emissions. Economic growth affects CO_2 emission in the short and long run. While there is a unidirectional links running from energy use to economic growth at short run. The paper shares best practices from Tunisia in terms of efficient use of renewable energy policy enablers, which may be contextualized in other emerging economies in order to keep sustainability and to achieve the green economy.

Keywords Economic growth · Energy consumption · CO_2 emissions · Renewable energy · Granger causality

JEL Classification Q43 · Q53 · Q56

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1 Introduction

Industrial revolution and rapid economic growth in countries have resulted into day's much discussed phenomena like global warming and climate change. The global increasing concern for environmental sustainability is visible in a public arena; the development strategy depends largely on economic growth which causes environmental degradation. In the past two decades, Kaygusuz (2009) has indicated the increase of carbon dioxide emissions is considered one of the main causes of global warming and climatic instability. The prevalence of such problems is higher in countries such as Tunisia, where economic growth, energy security and environmental sustainability are simultaneously important. On the other hand, the use of energy natural resources as inputs in the development or production process is a problem.

Tunisia, as a developing country, economic growth represents an interesting case where it faces the difficulty to fulfill the needs of energy demand. Industries may increase pollution in developing countries such as Tunisia, due to the increased production of emissions intensity to export goods to developed countries. Currently, the economy of Tunisia is diverse economy, ranging from agriculture, fisheries, mining, manufacturing, textiles, and petroleum products, to tourism. Tunisia is not like some North African countries as Algeria and Libya which are mostly endowed with rich hydrocarbon resources. Tunisia is endowed with multi and excellent renewable resources. Thus, Tunisia should be more keen to invest in renewable energy generation projects to minimize spending and dependence on foreign energy sources. Therefore, analyses of economic and environmental impacts of concerned variables are needed to address this research gap and to improve the design and accept the energy renewable policy.

The main objective of present study is to examine the long run and the relationship between economic growth, renewable energy consumption, energy consumption and environmental pollution measured by CO_2 emissions in Tunisia during the period 1990–2015. This object is achieved by the following steps: First, stationarity and Johansen co-integration are tested; second, error-correction models are estimated to test for the Granger causality between the two variables. The rest of this article is structured as follows: After the section (1) which is the introduction, this paper includes five additional sections: section (2) is a literature review; section (3) presents the data source and methodological framework; section (4) presents the empirical results and interpretation. finally, section (5) present the conclusion and policy implications.

2 Literature review

Nowadays, the causal relationship among energy, environment pollution and economic growth has been well established in empirical studies, which use diverse approaches, methods, variables and different countries and regions. However, the empirical results of these works are contradictory. Certain researchers argue that exists a bidirectional causality between energy use and economic growth; while some studies showed that exists a unidirectional relationship from energy to economic growth where the reverse. From the perspective of environmental economics, the relation among these variables depicts a matter of great importance. To the extent of our knowledge, only a single study based on the scenario of Bangladesh was conducted involving all three aspects: Energy, CO_2 emissions and economic growth. On the other hand, there has had many difference between the results obtained. For example, Kraft and Kraft 1978) investigated the link between energy use and economic growth in the United States; they concluded that GNP leads to energy consumption. This seminal work was followed by an impressive number of studies on the same topic.

Several empirical literature, such as Jbir and Zouari-Ghorbel (2009), Menyah and Wolde-Rufael (2010), Pao and Yu (2011), Akpan and Akpan (2011), Alam et al. (2012), Kais and Hammami (2014), Mbarek et al. (2014) and Salahuddin and Gow (2014), Mbarek et al. (2015), Saidi and Hammami (2015a, b), investigate the relationship between energy consumption, greenhouse gas (GHG) emissions and economic growth for a number of developing and developed countries. The recent research on energy use and economic development ensures a stream of information regarding the causality sense between renewable energy and economic growth. Renewable energy consumption is inherently linked to sustainable development, emissions reductions and energy security (Reboredo 2015). Every country has different effects of renewable energy use; some countries report economic growth fetches handsome contribution in renewable energy consumption, while for some countries this source of energy contribute in economic growth. In addition, several others studies have found no relationship and/or two-way causal relationship between economic growth and renewable energy use. The summary of empirical studies regarding the causality relationship between renewable energy and economic growth are presented in Table 1.

We can classify the literature considered in two categories. The first category comprises studies which examine the nexus between energy and economic growth, and the second category comprises the studies that examine the relationship between renewable energy and economic growth. In this framework, Narayan and Smyth (2008), Bowden and Payne (2010), Belloumi (2009), Belke et al. (2011), Yildirim et al. (2012), Al-mulali et al. (2013), and Sebri (2015) proved the validity of the growth hypothesis implies an increase, respectively (decrease) in energy consumption leads to an increase (decrease) in real GDP. In this case, the energy box the GDP and the economy is greatly dependent on energy; Belloumi (2009), Apergis and Payne (2010a, b), Apergis and Payne (2011), Ozturk et al. (2010), Eggoh et al. (2011), Apergis and Payne (2012), Tugcu et al. (2012), Al-mulali et al. (2013), Pao and Fu (2013), Sebri (2015) proved the validity of the feedback hypothesis suggests a two-way causal relationship between energy consumption and real GDP so that an implementation of an efficient consumer policy has no negative effect on real GDP; Huang et al. (2008), Sadorsky (2009), Ozturk et al. (2010), Al-mulali et al. (2013), Pao and Fu (2013), Ocal and Aslan (2013a, b), and Sebri (2015) proved the validity of the conservation hypothesis involves that energy conservation policies resulting in reduced energy consumption have no negative effects on real GDP. This hypothesis is checked whether an increase in GDP leads to an increase in energy consumption, and Menegaki (2011), Tugcu et al. (2012), Yildirim et al. (2012) and Sebri (2015) proved the validity of the neutrality hypothesis considers that the energy consumption is only a fraction of the components of the production and its effect on real GDP is low or zero. This hypothesis is confirmed by the absence of a causal relationship between energy consumption and real GDP. We summarize the studies that based on the link between economy, energy use and CO_2 emissions discussed above in the following Table 1.

3 Data source and methodological framework

3.1 Data sources

The annual data used in this the paper are taken from the World Development Indicator (WDI, 2014-CD-ROM) for Tunisia, and cover 1990–2015. The variables used are the

Table 1 Summary of the studies based on energy use, renewable energy and economic growth

Authors	Methodology	Countries and period of study	Variables	Conclusion(s)
First nexus: energy use-economic growth				
Huang et al. (2008)	Generalized Method of Moment System	82 countries, (1972–2002)	GDP; EC	Conservation hypothesis
Narayan and Smyth (2008)	Panel cointegration and Granger causality	G7, (1972–2002)	GDP; EC	Growth hypothesis
Sari et al. (2008)	ARDL approach	USA, (1969-1999)	EC; GDP	Conservation hypothesis
Belloumi (2009)	Granger causality test	Tunisia, (1971–2004)	GDP; EC	Growth and the feedback hypothesis
Ozturk et al. (2010)	Panel cointegration and panel causality tests	51 countries, (1971–2005)	GDP; EC	Feedback and the conversation hypothesis
Belke et al. (2011)	Panel cointegration; VECM; Granger causality	25 OECD countries (1981–2007)	GDP; EC	Feedback hypothesis
Eggoh et al. (2011)	Panel cointegration and panel causality tests	21 African countries, (1970–2006)	EC; GDP	Feedback hypothesis
Second nexus: renewable energy consumption-economic growth				
Bowden and Payne (2010)	Toda–Yamamoto procedure	US, (1949–2006)	REC; GDP	Growth hypothesis
Apergis and Payne (2010a)	Panel ECM (Granger causality)	13 Eurasia countries, (1992–2007)	REC; GDP	Feedback hypothesis
Apergis and Payne (2010b)	Panel Granger causality F	20 OECD countries, (1985–2005)	REC;GDP	Feedback hypothesis
Sadorsky (2009)	Bivariate panel error correction model	18 emerging countries, (1994–2003)	REC; GDP	Conservation hypothesis
Apergis and Payne (2011)	Panel ECM	6 Central American, (1980–2006)	REC; GDP	Feedback hypothesis
Menegaki (2011)	Multivariate panel framework	27 European countries, (1997–2007)	REC; EG	Neutrality hypothesis
Apergis and Payne (2012)	Panel error correction model	80 countries, (1990–2007)	EC; REC; EG	Feedback hypothesis in both the short
Tugcu et al. (2012)	Hatemi-J causality tests	G-7 Countries, (1980–2009)	REC; EG	Neutrality hypothesis for France, Italy, Canada and USA, Feedback hypothesis for England and Japan
Yildirim et al. (2012)	Toda–Yamamoto and Hatemi-J causality tests	U.S.A, (1949–2010)	REC; EG	Neutrality hypothesis, Growth hypothesis

Table 1 continued

Authors	Methodology	Countries and period of study	Variables	Conclusion(s)
Al-mulali et al. (2013)	Fully modified OLS tests	108 countries, (1980–2009)	REC; EG	79% of the countries feedback hypothesis 19% of the countries neutrality hypothesis, 2% of the countries conservation and growth hypothesis.
Pao and Fu (2013)	Error correction model	Brazil, (1980–2010)	EC; REC; EG	Feedback Hypothesis, Conservation hypothesis
Ocal and Aslan (2013a, b)	ARDL approach	Turkey, (1990–2010)	REC; EG	Conservation hypothesis
Sebri (2015)	Multinomial logit model and causality tests	40 Providing, (2012–2013)	REC; EG	Conservation, growth, neutrality and feedback hypotheses

EC energy consumption, *REC* renewable energy consumption, *GDP* real GDP, *EG* economic growth

Table 2 Descriptive statistics of variables

	LNGDP	LNREC	LNEU	$LNCO_2$
Mean	8.076463	2.652134	6.666007	0.755899
Median	8.071525	2.656751	6.695338	0.769269
Maximum	8.353199	2.776954	6.882273	0.964143
Minimum	7.718190	2.568628	6.378355	0.486738
Std. Dev.	0.220192	0.041337	0.162554	0.138371
Skewness	−0.170419	0.389142	−0.327505	−0.213617
Kurtosis	1.581645	4.942574	1.725472	1.785235
Jarque–Bera	2.305228	4.744262	2.224581	1.796365
Probability	0.315810	0.093282	0.328805	0.407309
Sum	209.9880	68.95548	173.3162	19.65338
Sum Sq. Dev.	1.212115	0.042719	0.660594	0.478667
Observations	26	26	26	26

economic growth (GDP) [proxied in GDP per capita (constant 2005 US$)], CO_2 emissions (CO_2) (measured in metric tons per capita), energy use (EU) (measured in kilogram (kg) of oil equivalent per capita), and Renewable energy consumption (REC) (measured in 1000 metric tons of oil equivalent). The descriptive statistics Mean, Median, Maximum, and Minimum of these variables are recorded below in Table 2.

A descriptive analysis of research variables shows that the average of GDP per capita in Tunisia is 8.076. The variables of renewable energy consumption are close to the average level (2.652). We check multicollinearity possible between the independent variables in our model by using the correlation matrix (Table 3). The variables of energy use and CO_2 emissions are correlated positively on GDP per capita, but the renewable energy consumption is correlated with a negative manner on GDP per capita. In addition, energy use and CO_2 emissions are negatively correlated to the renewable energy consumption. Finally, there is a positive correlation between CO_2 emissions and energy use.

Table 3 Correlation matrix between the variables. *Source* author

	LNGDP	LNREC	LNEU	$LNCO_2$
LNGDP	1.000000			
LNREC	−0.322284	1.000000		
LNEU	0.988422	−0.357729	1.000000	
$LNCO_2$	0.975003	−0.362630	0.965696	1.000000

GDP Gross domestic product, *REC renewable energy consumption*, *EU* energy use, CO_2 CO_2 emissions

3.2 Methodological framework

We examine the causality relationships short and long run between economic growth, energy use and CO_2 emissions and renewable energy consumption in case of Tunisia. The analysis begins with the examination of the stationary properties of the variables by employing a battery of unit root tests, co-integration tests and Granger causality tests. For our case, the studied variables take the linear form compared by other variables as energy prices that generally take the non linear form. It for this reason we a linear model to resolve this problem. An important paper by Beckmann et al. (2014) investigated the relationship between the spot and futures prices of energy commodities from a new perspective. In fact, the movements of global commodity prices take the nonlinear form. Unlike, we have studies the dynamic links between energy consumption and economic growth that take a linear form according to several studies in this area, Menegaki (2011), Tugcu et al. (2012), Yildirim et al. (2012), Sebri (2015) and Mbarek et al. (2015).

3.2.1 Unit root tests

The most effective method to determine the order of integration of a series is based on the unit root tests. The unit root tests can detect the presence of unit root in a series. Two unit root tests are usually used, i.e. the test Augmented Dickey–Fuller (ADF) (1979) and the Phillips–Perron (PP) (1988).

(a) Augmented Dickey–Fuller unit root tests
It consists of testing the null hypothesis H_0: $\rho = 1$ against the alternative hypothesis H_1: $\rho < 1$. It is based on the least squares estimation of three models:

$$\Delta x_t = (\rho - 1)x_{t-1} + \sum_{j=2}^{k} \theta_j \Delta_{t-j+1} + \varepsilon_t\text{: Process no trend and no constant} \quad (1)$$

$$\Delta x_t = (\rho - 1)x_{t-1} + \sum_{j=2}^{k} \theta_j \Delta_{t-j+1} + \alpha + \varepsilon_t\text{: Process no trend and with constant} \quad (2)$$

$$\Delta x_t = (\rho - 1)x_{t-1} + \sum_{j=2}^{k} \theta_j \Delta_{t-j+1} + \alpha + \beta t + \varepsilon_t\text{: Process with trend and constant} \quad (3)$$

(b) The Phillips–Perron test
This test provides a nonparametric statistical correction of Augmented Dickey–Fuller in the presence of autocorrelation of the unknown form (AR (p), MA (q) and ARMA (p, q)). It has the following three models:

$$\Delta x_t = (\rho - 1)x_{t-1} + \varepsilon_t\text{: Process no trend and no constant} \tag{4}$$

$$\Delta x_t = (\rho - 1)x_{t-1} + \alpha + \varepsilon_t\text{: Process no trend and with constant} \tag{5}$$

$$\Delta x_t = (\rho - 1)x_{t-1} + \alpha + \beta t + \varepsilon_t\text{: Process with trend and constant} \tag{6}$$

As in the case of the Dickey–Fuller test, the hypotheses to be tested are the same.

3.2.2 Johansen co-integration test

This is the step that follows the preliminary tests check non-stationarity of the series. The two-step approach of Engle and Granger is very restrictive. Indeed, this approach is applicable only in the case of a single co-integration relationship (so only one co-integrating vector). In addition, it poses a standardization problem; it can lead to different results depending on whether one considers the combination $z_t = x_t - a - by_t$ or $z_t = y_t - a - bx_t$.

As an alternative to the approach of Engle and Granger, it instead uses the co-integration test of Johansen. This test determines the number of long-term equilibrium relationship between integrated variables same regardless of the normalization used. The Johansen co-integration test uses two statistics to determine the number of co-integrating vectors r:

- Trace test for the existence of assumption of no co-integrating vectors given by:

$$Trace = -T \sum_{i=r+1}^{P} ln\left(1 - \hat{\lambda}_i\right)$$

- Testing the maximum eigenvalue for the existence of assumption exactly vectors of co-integration: $\lambda_{max} = Tln\left(1 - \hat{\lambda}_{r+1}\right)$.

3.2.3 The error correction model

Accept co-integration, it is to accept the fact that there is a steady state relationship between the four sets of variables that have a common tendency to move in the same direction. Any momentary deviation from balance is considered random. According to Granger representation theorem, all co-integrated system implies the existence of an error correction mechanism that prevents too variables deviate from their long-term equilibrium. If cointegration allows clarify the reality and nature of discrepancies between four series theoretically linked and to model the behavior of these variables, the error correction model can explain and deduce the mechanism. In a way general, you can simply write the error correction model as follows:

$$\Delta GDP_t = \alpha_1 z_{t-1} + lagged(\Delta GDP_t, \Delta REC_t, \Delta EU_t, \Delta CO2_t) + \varepsilon_{1t} \tag{7}$$

$$\Delta REC_t = \alpha_2 z_{t-1} + lagged(\Delta GDP_t, \Delta REC_t, \Delta EU_t, \Delta CO2_t) + \varepsilon_{2t} \tag{8}$$

$$\Delta EU_t = \alpha_3 z_{t-1} + lagged(\Delta GDP_t, \Delta REC_t, \Delta EU_t, \Delta CO2_t) + \varepsilon_{3t} \tag{9}$$

$$\Delta CO2_t = \alpha_4 z_{t-1} + lagged(\Delta GDP_t, \Delta REC_t, \Delta EU_t, \Delta CO2_t) + \varepsilon_{4t} \tag{10}$$

where z_{t-1} is the term of error correction coming from the estimate of the relationship of co-integration, ε is a term of stationary error; $|\alpha_1| + |\alpha_2| + |\alpha_3| + |\alpha_4| \neq 0$.

3.2.4 Causality test

Engle and Granger (1991) showed that if the variables are integrated, the classic test of Granger, based on the VAR is no longer appropriate. They recommend doing this using the error correction model. In addition, the causality test based on the vector model with error correction present the advantage of a causal relationship even if no estimated coefficient of lagged variables of interest is significant. Taking into account relations (7), (8), (9) and (10), we can rewrite Eqs. (11), (12), (13) and (14) as follows:

$$\Delta GDP_t = \alpha + \sum_{i=1}^{k} \theta_1 \Delta GDP_{t-i} + \sum_{i=1}^{k} \tau_1 \Delta REC_{t-i} + \sum_{i=1}^{k} \rho_1 \Delta EU_{t-i} + \sum_{i=1}^{k} \sigma_1 \Delta CO2_{t-i} + \varphi_1 z_{t-1} + \varepsilon_t \tag{11}$$

$$\Delta REC_t = \beta + \sum_{i=1}^{k} \tau_2 \Delta REC_{t-i} + \sum_{i=1}^{k} \theta_2 \Delta GDP_{t-i} + \sum_{i=1}^{k} \rho_2 \Delta EU_{t-i} + \sum_{i=1}^{k} \sigma_2 \Delta CO2_{t-i} + \varphi_2 z_{t-1} + \vartheta_t \tag{12}$$

$$\Delta EU_t = \gamma + \sum_{i=1}^{k} \rho_3 \Delta EU_{t-i} + \sum_{i=1}^{k} \theta_3 \Delta GDP_{t-i} + \sum_{i=1}^{k} \tau_3 \Delta REC_{t-i} + \sum_{i=1}^{k} \sigma_3 \Delta CO2_{t-i} + \varphi_3 z_{t-1} + \mu_t \tag{13}$$

$$\Delta CO2_t = \delta + \sum_{i=1}^{k} \sigma_4 \Delta CO2_{t-i} + \sum_{i=1}^{k} \theta_4 \Delta GDP_{t-i} + \sum_{i=1}^{k} \tau_4 \Delta REC_{t-i} + \sum_{i=1}^{k} \rho_4 \Delta EU_{t-i} + \varphi_4 z_{t-1} + \pi_t \tag{14}$$

By using the vector model error correction Eqs. (11), (12), (13) and (14), GDP_tdoes not cause REC_t Granger if $\theta_2 = \varphi_2 = 0$; REC_t does not cause GDP_t if $\tau_1 = \varphi_1 = 0$; GDP_t does not cause EU_t Granger if $\theta_3 = \varphi_3 = 0$; EU_t does not cause GDP_t Granger if $\rho_1 = \varphi_1 = 0$; GDP_t does not cause $CO2_t$ Granger if $\theta_4 = \varphi_4 = 0$; $CO2_t$ does not cause GDP_t Granger if $\sigma_1 = \varphi_1 = 0$; REC_t does not cause EU Granger if $\tau_3 = \varphi_3 = 0$; EU_t does not cause REC_tGranger if $\rho_2 = \varphi_2 = 0$; REC_t does not cause $CO2_t$ Granger if $\tau_4 = \varphi_4 = 0$; $CO2_t$ does not cause REC_t Granger if $\sigma_2 = \varphi_2 = 0$; CO_{2t} does not cause EU_t Granger if $\sigma_3 = \varphi_3 = 0$; EU_t does not cause $CO2_t$ Granger if $\rho_4 = \varphi_4 = 0$.

4 Empirical results and interpretation

4.1 Unit root tests

The results of the unit root tests are presented in Table 4. They show that the four series studied namely economic growth (LNPIB), consumption of renewable energy (LNREC), the use of energy (LNEU) and CO_2 emissions ($LNCO_2$) are integrated of order 1.

Table 4 Result of unit root test

Variables	Model	Level		1st difference	
		t statistic	Prob.*	t statistic	Prob.*
ADF test					
LNGDP	2	−1.489075	0.5225	−3.925292	0.0065*
LNREC	2	−3.102023	0.1427	−3.540496	0.0182**
LNEU	2	−2.345794	0.1685	−11.26641	0.0000*
$LNCO_2$	2	−0.729110	0.8208	−9.926700	0.0000*
Phillips–Perron test					
LNGDP	5	−1.450155	0.5416	−3.925292	0.0065*
LNREC	5	−2.320025	0.1738	−6.044482	0.0000*
LNEU	5	−1.215975	0.6510	−11.21157	0.0000*
$LNCO_2$	5	−1.692524	0.4226	−10.29405	0.0000*

** and * Denote 5 and 1% significance level, respectively

Indeed the unit root hypothesis tested in Eq. (3) with four LNGDP series LNREC, LNEU and LNCO in level is accepted at the 5% threshold. If we admit that $\rho = 1$ in the Eq. (3), while the β coefficient is significantly zero. We test the unit root again in Eq. (2) where β is disappeared. We accept once again the unit root hypothesis. The nullity of constant α being rejected, when it is assumed that $\rho = 1$ in Eq. (2), case of the consumption of renewable energy (LNREC), the use of energy (LNEU) and emissions CO_2 ($LNCO_2$), we retain those for variable model (2) to increase the Dickey–Fuller test. It is concluded that the two series are integrated of order 1 level. By performing of the Augmented Dickey–Fuller test on the series in first differences, with the same procedure, we retain the model (1) for both series. The unit root hypothesis is rejected in this case (at 1% ADF, t stat = 3925 for LGDP; at 5% ADF, t stat = −3540 for LNREC; at 1% ADF, t-stat = 11,266 to LNEU and at 1% ADF, t stat = 9926 for $LNCO_2$).

The Phillips-Perron test applied the same strategy on the four series confirms this characterization at the 1% level with the models (4), (5) and (23). The unit root tests confirm the impossibility to reject the hypothesis that the four variables LNGDP, LNREC, LNEU $LNCO_2$ and are integrated of order 1 (I (1)). It is, therefore, possible that they are co-integrated.

4.2 Results of co-integration test

We recall that the different sub-models tested of general model are:

- *Model 1* there are no constants and linear trends in the VAR and co-integration relationship does not include either of constant and linear trends;
- *Model 2* there is no constant and linear trend in the VAR, but the relationship of co-integration includes a constant (no linear trend);
- *Model 3* there are constant (no linear trends) in the VAR and relationship of co-integration includes a constant (not a linear trend);
- *Model 4* there are constant (no linear trends) in the VAR and the relationship of co-integration includes a linear constant;
- *Model 5* there are constants and trends in the VAR and the relationship of co-integration includes a constant and a linear trend.

Table 5 Choice of number of delays k

	AIC	SC
r = 0	−13.03359	−12.83611
r = 1	−17.38761	−16.40023[a]
r = 2	−17.82445	−16.04715
r = 3	−17.82831[a]	−15.26111

AIC Akaike information criterion, *SC* Schwarz information criterion

[a] Indicates lag order selected by the criterion

Table 5 Presents the number of delays. By testing these different sub-models for different values of k, the Akaike information criterion is optimized for the models, r = 2 and k = 3. This model indicates the existence of a quadratic trend in each component of the system that is level, and then the system is written in first differences.

By testing these sub-models with a delay k = 3, we find that the optimized model is (or constant or trend), r = 2, k = 3. The Johansen test will be conducted from this model r = 2 A delay with k = 3. The test results are shown in Table 6.

This table shows that the null hypothesis None, At most 1 and At most 2 (for the test track and the maximum eigenvalue test) is rejected at the 1%. Also, the null hypothesis At most 3 (for trace test and the test of the maximum eigenvalue) is rejected at the 5%. Both Johansen co-integration tests confirm the existence of a co-integration relationship.

4.3 Estimation of error correction model

The representation theorem of Engle and Granger, we said, demonstrates that the non-stationary series, especially those that have a unit root, must be represented in the form of error correction model if they are co-integrated, that is to say if there is a stationary linear combination between them. The estimated of the vector error correction model passes by determining the long-term relationship below, where the GDP variable is normalized:

$$LNGDP_{-1} = \underset{(0.305)}{0.1089 LNREC_{-1}} - \underset{(0.108)}{0.3211 LNEU_{-1}} - \underset{(0.144)}{0.2255 LNCO2_{-1}} - 0.0041$$

The estimate of error correction model is given in the table below (Table 7). The value in parenthesis represents the Student statistic associated with the coefficient estimated LNREC, LNEU and $LNCO_2$. According to this relationship, in the long term, GDP and consumption of renewable energy, energy use and CO_2 emissions go hand in hand because the GDP coefficient is positive. Thus, in the long term, an increase of 1% of GDP leads to an increase in renewable energy consumption, energy use and CO_2 emissions of 1.33; 0.36 and 1.12%, respectively. The Jarque–Bera statistic indicates in fact that residues of the error correction model are normally distributed. In addition, the Z_{t-1} error correction term parameter is negative and significant in the equation of GDP, confirming the existence of a long-term relationship between renewable energy consumption, energy use, CO_2 emissions and growth.

The CO_2 emissions negatively affect GDP and the impact of renewable energy consumption is positive on GDP. This implies that a 1% increase in CO_2 and renewable energy decreases and increases GDP by 0.28 and 0.16%, respectively.

Table 6 Johansen cointegration test

Hypothesized no. of CE(s)	Eigen value	Trace statistic	0.05 Critical value	Prob.**
Unrestricted co-integration rank test (trace)				
None*	0.835019	101.1350	47.85613	0.0000
At most 1*	0.821301	61.49263	29.79707	0.0000
At most 2*	0.587228	23.60753	15.49471	0.0024
At most 3*	0.171559	4.140615	3.841466	0.0419
Hypothesized no. of CE(s)	Eigen value	Max-Eigen statistic	0.05 Critical value	Prob.**
Unrestricted cointegration rank test (maximum Eigen value)				
None*	0.835019	39.64240	27.58434	0.0009
At most 1*	0.821301	37.88510	21.13162	0.0001
At most 2*	0.587228	19.46692	14.26460	0.0069
At most 3*	0.171559	4.140615	3.841466	0.0419

Notes ** and * indicate significance at the 5% and 1% level, respectively

4.4 Granger causality test

We have seen that the existence of a co-integration relationship between these four variables resulted in the existence of a causal relationship between them in at least one direction. This causal relationship is discussed here using the Granger causality test based on vector error correction model. The results of this test are presented in the following Table 8.

They were obtained in reality using the Wald coefficient restriction test based on each equation of error correction model. Indeed, the Wald test gives the possibility to integrate in the null hypothesis the coefficient of the term error correction. The Granger causality test reveals the existence of a unidirectional relationship running from GDP growth to the renewable energy consumption. The results are confirmed with the results of Ocal and Aslan (2013a, b) and Xu (2016). In addition, there is a unidirectional causality running from energy consumption to GDP per capita. The result also shows that there is a bidirectional relationship between CO_2 emissions and GDP per capita between the renewable energy consumption and energy consumption and between CO_2 emissions and energy consumption. The results are in line with the results of the Kim et al. (2010), Alam et al. (2011), Saboori and Sulaiman (2013) and Long et al. (2015). Unidirectional relationship running from CO_2 emissions to renewable energy consumption is found. The result is in line with the conclusions of Farhani (2013)

5 Conclusion and policy implications

The main objective of this study is to investigate the relationship between economic growth, energy use, carbon dioxide emissions and renewable energy consumption in Tunisia using data from 1990 to 2015. Empirically, we tested the order of integration of the series (unit root tests) to ensure that they follow a random walk (only scope of Granger representation theorem). Then we tested the co-integration to determine the existence of a steady state relationship between the variables. Finally, we estimated the error correction model which aims to account in the same equation of a possible deviation from a long-term balance and short-term adjustment process of balance.

Table 7 Vector error correction model (VECM)

Variables	ΔLNGDP		ΔLNREC		ΔLNEU		$\Delta LNCO_2$	
	Coefficient	*p* value	Coefficient	*p* value	Coefficient	*p* value	Coefficient	*p* value
Z_{t-1}	−.0976996*	(**0.001**)	−.0716352	(0.140)	−.1416093**	(**0.023**)	−.1329163**	(**0.042**)
$\Delta LNGDP_{t-1}$	0.3697229***	(**0.052**)	0.6572778	(0.231)	0.1494154	(0.709)	1.126041*	(**0.007**)
$\Delta LNGDP_{t-2}$	0.3858315	(0.149)	1.336111***	(**0.082**)	0.3660419**	(**0.015**)	0.4189164	(0.478)
$\Delta LNREC_{t-1}$	0.1089883	(0.305)	−.0805033	(0.792)	0.1134773	(0.611)	−.1459125	(0.534)
$\Delta LNREC_{t-2}$	0.1932791**	(**0.031**)	−.6563114**	(**0.011**)	0.0726007	(0.699)	0.0504107	(0.798)
$\Delta LNEU_{t-1}$	−.3211284	(0.108)	0.7283383	(0.205)	1.388187*	(**0.001**)	−.8963104**	(**0.042**)
$\Delta LNEU_{t-2}$	−.1172494	(0.507)	−.0367032	(0.942)	0.5533415	(0.136)	−.1005663	(0.797)
$\Delta LNCO2_{t-1}$	−.2255782	(0.144)	−.748658***	(**0.092**)	0.2991959	(0.357)	−.2281011	(0.503)
$\Delta LNCO2_{t-2}$	−.2865457	(**0.012**)	−.6869746**	(**0.036**)	−.0101177	(0.966)	0.162665	(0.516)
Constant	−.0041561	(0.575)	−.0322479	(0.130)	0.002747	(0.860)	−.0172517	(0.291)
R-squared	0.9108		0.4865		0.7524		0.7617	
Jarque–Bera test	1.314	0.51839	0.140	0.93237	0.567	0.75312	0.058	0.97131

Notes *, ** and *** denote 1%, 5% and 10% level of significant

Table 8 Granger causality test

Null hypothesis	Obs	F Statistic	Prob.
LNREC does not Granger Cause LNGDP	23	1.75002	0.1972
LNGDP does not Granger Cause LNREC		2.46987	**0.0993*****
LNEU does not Granger Cause LNGDP	23	3.36947	**0.0447****
LNGDP does not Granger Cause LNEU		1.02250	0.4088
$LNCO_2$ does not Granger Cause LNGDP	23	5.28028	**0.0101****
LNGDP does not Granger Cause $LNCO_2$		5.01061	**0.0123****
LNEU does not Granger Cause LNREC	23	1.31922	**0.0302****
LNREC does not Granger Cause LNEU		2.17968	**0.0130****
$LNCO_2$ does not Granger Cause LNREC	23	1.21741	**0.0335****
LNREC does not Granger Cause $LNCO_2$		1.38862	0.2824
$LNCO_2$ does not Granger Cause LNEU	23	2.51359	**0.0953*****
LNEU does not Granger Cause $LNCO_2$		3.08816	**0.0570*****

** and *** denotes rejection of the null hypothesis at the 5% threshold and 10%

Our empirical findings of the Causality test indicate that there is a bidirectional causal relationship between energy use and CO_2 emissions and a bidirectional causal relation between CO_2 emissions and renewable energy consumption. Moreover, the results indicate that there is a unidirectional relationship running from energy consumption to GDP per capita and from CO_2 emissions to renewable energy consumption.

One of the main tasks of energy policy is energy conservation, which means more efficient consumption of energy and a reduction of CO_2 emissions through alternative energy options. In addition, the empirical results of this paper provide policymakers a better understanding of energy use–economic growth nexus; energy use-CO_2 emissions nexus and renewable energy consumption-economic growth nexus to formulate energy and climate policies in Tunisia. If an increase in economic growth brings about an increase in energy consumption, the externality of energy use will set back economic growth. Under this circumstance, a conservation policy is necessary. In addition, the findings of this study have important policy implications and it shows that this issue still deserves further attention in future research.

References

Akpan, G.E., Akpan, U.F.: Electricity consumption, carbon emissions and economic growth in Nigeria. Int. J. Energy Econ. Policy **2**(4), 292–306 (2011)

Alam, M.J., Begum, I.A., Buysse, J., Rahman, S., Van Huylenbroeck, G.: Dynamic modeling of causal relationship between energy consumption, CO_2 emissions and economic growth in India. Renew. Sustain. Energy Rev. **15**(6), 3243–3251 (2011)

Alam, M.J., Begum, I.A., Buysse, J., Huylenbroeck, G.V.: Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. Energy Policy **45**, 217–225 (2012)

Al-mulali, U., Fereidouni, H.G., Lee, J.Y., Sab, C.N.B.C.: Examining the bi-directional long run relationship between renewable energy consumption and GDP growth. Renew. Sustain. Energy Rev. **22**, 209–222 (2013)

Apergis, N., Payne, J.E.: Renewable energy consumption and growth in Eurasia. Energy Econ. **32**(6), 1392–1397 (2010a)

Apergis, N., Payne, J.E.: Renewable energy consumption and economic growth: evidence from a panel of OECD countries. Energy Policy **38**, 656–660 (2010b)

Apergis, N., Payne, J.E.: The renewable energy consumption-growth nexus in Central America. Appl. Energy **88**, 343–347 (2011)
Apergis, N., Payne, J.E.: Renewable and non-renewable energy consumption- growth nexus: evidence from a panel error correction model. Energy Econ. **34**, 733–738 (2012)
Beckmann, J., Belke, A., Czudaj, R.: Regime-dependent adjustment in energy spot and futures markets. Econ. Modell. **40**, 400–409 (2014)
Belke, A., Dreger, C., Dobnik, F.: Energy consumption and economic growth—neinsights into the cointegration relationship. Energy Econ. **33**(5), 782–789 (2011)
Belloumi, M.: Energy consumption and GDP in Tunisia: cointegration and causality analysis. Energy Policy **37**, 2745–2753 (2009)
Bowden, N., Payne, J.E.: Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US. Energy Sources Part B **5**(4), 400–408 (2010)
Eggoh, J.C., Bangake, Ch., Rault, C.: Energy consumption and economic growth revisited in African countries. Energy Policy **39**, 7408–7421 (2011)
Engle. R.F., Granger, C.W.J. (eds.): Long-run economic relationships: readings in cointegration. Oxford University Press, Oxford (1991)
Farhani, S.: Renewable energy consumption, economic growth and CO2 emissions: evidence from selected MENA countries. Energy Econ. Lett. **1**(2), 24–41 (2013)
Huang, B., Hwang, M.J., Yang, C.W.: Causal relationship between energy consumption and GDP growth revisited: a dynamic panel data approach. Ecol. Econ. **66**, 41–54 (2008)
Jbir, R., Zouari-ghorbel, S.: Recent oil price shock and the Tunisian economy. Energy Policy **37**, 1041–1051 (2009)
Kaygusuz, K.: Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey. Renew. Sustain. Energy Rev. **13**, 253–270 (2009)
Kim, S.W., Lee, K., Nam, K.: The relationship between CO2 emissions and economic growth: the case of Korea with nonlinear evidence. Energy Policy **38**(10), 5938–5946 (2010)
Kraft, J., Kraft, A.: Note and Comments: on the Relationship between Energy and GNP. The Journal of Energy and Development **3**, 401–403 (1978)
Long, X., Naminse, E.Y., Du, J., Zhuang, J.: Nonrenewable energy, renewable energy, carbon dioxide emissions and economic growth in China from 1952 to 2012. Renew. Sustain. Energy Rev. **52**, 680–688 (2015)
Mbarek, M.B., Ali, N.B., Feki, R.: Causality relationship between CO_2 emissions, GDP and energy intensity in Tunisia. Environ. Dev. Sustain. **16**, 1253–1262 (2014)
Mbarek, M.B., Khairallah, R., Feki, R.: Causality relationships between renewable energy, nuclear energy and economic growth in France. Environ. Syst. Decis. **35**(1), 133–142 (2015)
Menegaki, A.N.: Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. Energy Econ. **33**, 257–263 (2011)
Menyah, K., Wolde-Rufael, Y.: Energy consumption, pollutant emissions and economic growth in South Africa. Energy Econ. **32**, 1374–1382 (2010)
Narayan, P.K., Smyth, R.: Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks. Energy Econ. **30**(5), 2331–2341 (2008)
Ocal, O., Aslan, A.: Renewable energy consumption–economic growth nexus inTurkey. Renew. Sustain. Energy Rev. **28**, 494–499 (2013a)
Ocal, O., Aslan, A.: Renewable energy consumption–economic growth nexus in Turkey. Renew. Sustain. Energy Rev. **28**, 494–499 (2013b)
Ozturk, I., Aslan, A., Kalyoncu, H.: Energy consumption and economic growth relationship: evidence from panel data for low and middle income countries. Energy Policy **38**, 4422–4428 (2010)
Pao, H.-T., Fu, H.-C.: Renewable energy, non-renewable energy and economic growth in Brazil. Renew. Sustain. Energy Rev. **25**, 381–392 (2013)
Pao, H.T., Yu, H.C., Yang, Y.H.: Modeling the CO_2 emissions, energy use, and economic growth in Russia. Energy **36**, 5094–5100 (2011)
Reboredo, J.C.: Renewable energy contribution to the energy supply: is there convergence across countries? Renew. Sustain. Energy Rev. V **45**, 290–295 (2015)
Saboori, B., Sulaiman, J.: CO2 emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: a cointegration approach. Energy **55**, 813–822 (2013)
Sadorsky, P.: Renewable energy consumption and income in emerging economies. Energy Policy **37**, 4021–4028 (2009)
Saidi, K., Hammami, S.: Energy consumption and economic growth nexus: empirical evidence from Tunisia. Am. J. Energy Res. **2**(4), 81–89 (2014)

Saidi, K., Hammami, S.: The impact of CO2 emissions and economic growth on energy consumption in 58 countries. Energy Rep. **1**, 62–70 (2015a)
Saidi, K., Hammami, S.: The impact of energy consumption and CO2 emissions on economic growth: fresh evidence from dynamic simultaneous-equations models. Sustain. Cities Soc. **14**, 178–186 (2015b)
Salahuddin, M., Gow, J.: Economic growth, energy consumption and CO_2 emissions in Gulf Cooperation Council countries. Energy **73**, 44–58 (2014)
Sari, R., Ewing, B.T., Soytas, U.: The relationship between disaggregate energy consumption and industrial production in the United States: an ARDL approach. Energy Econ. **30**, 2302–2313 (2008)
Sebri, M.: Use renewables to be cleaner: meta-analysis of the renewable energy consumption-economic growth nexus. Renew. Sustain. Energy Rev. **42**, 657–665 (2015)
Tugcu, C.T., Ozturk, I., Aslan, A.: Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. Energy Econ. **34**, 1942–1950 (2012)
Xu, H. X.: Linear and nonlinear causality between renewable energy consumption and economic growth in the USA. J. Econ. Bus. **34**(2), 309–332 (2016)
Yildirim, E., Sarac, S., Aslan, A.: Energy consumption and economic growth in the USA: evidence from renewable energy. Renew. Sustain. Energy Rev. **16**, 6770–6774 (2012)