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*A multivariate analysis of the causal flow between renewable energy
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Abstract

This paper examines the causality linkages between economic growth, renewable energy consumption, CO₂ emissions and domestic investment in Tunisia between 1971 and 2010. Using the ARDL bounds testing approach to cointegration, long-run relationships between the variables are identified. The Granger causality analysis, on the other hand, indicates that there is bi-directional causality between renewable energy consumption and economic growth, which supports the feedback hypothesis in Tunisia. In addition, the quantity of CO₂ emissions collapses as a reaction to an increase in renewable energy consumption. These findings remain robust even when controlling for the presence of structural break. We conclude that more efforts should be undertaken to further develop a suitable infrastructure to the renewable energy sector, given its enhancing-effects on economic growth and reducing-effects on CO₂ emissions.

Keywords: ARDL, Economic growth, Granger causality, Renewable energy consumption, Structural break, Tunisia.

JEL Classifications: C3, Q4.

1. Introduction

During the last decades, crude oil prices have sharply fluctuated up and down. In importing-oil economies, the volatility of crude oil prices represents an important source of macroeconomic uncertainty and instability. In addition, the consumption of fossil fuels is considered as the main source of environmental pollution via the emissions of CO₂ and other greenhouse gases. This has been especially amplified during the last decades, given that the industrial sectors in emerging economies are more and more growing. The boom in polluting emissions and the volatility of crude oil prices have incited countries to invest in the renewable energy sources. This energy kind presents two main advantages. On the one hand, it is less expensive than non-renewable energy, since it is essentially based on inexhaustible natural sources. On the other hand, the renewable energy is considered as the most environmentally friendly type of energy (Demirbas, 2008). According to the latest Renewables 2013 Global Status Report published by the Renewable Energy Policy Network for the 21st century, the global renewable energy supplied about 19% of total final energy consumption in 2011 (REN21, 2013). The same report indicates also that big renewable energy projects are being launched in almost all over the world.

Academically speaking, the macroeconomic effects of renewable energy consumption have recently been investigated. The link between renewable energy consumption and growth constitutes the main body of the related literature. Empirical studies on the topic divulge divergent results concerning the direction of causality between renewable energy consumption and economic growth. Four hypotheses linked to the causal relationship between renewable energy consumption and economic growth are considered in the literature. First, the feedback hypothesis exists if there is bi-directional causality between economic growth and renewable energy consumption. Thus, they are considered as complement. This hypothesis is confirmed, among others, by Apergis and Payne (2012), Tugcu et al. (2012) and Sebri and Ben Salha (2013). Second, the growth hypothesis states that causality runs from renewable energy consumption to economic growth. That is, policies aiming to reduce renewable energy consumption may exert negative effects on economic growth. Studies conducted by, for example, Bildirici (2013), Yildirim et al. (2013) and Ben Aïssa et al. (2013) give support to this hypothesis. Third, the conservation hypothesis emphasizes that economic growth causes renewable energy consumption, whereas the reverse is not true. Hence, an increase in economic growth positively impacts the consumption of renewable energy. Such hypothesis is confirmed by many studies, including Menyah and Wolde-Rufael (2010),

Sadorsky (2009a) and Sadorsky (2009b). Finally, the neutrality hypothesis, supported by, among others, Menegaki (2011) and Bowden and Payne (2010), suggests that a change occurred in one of the two variables does not affect the other.

The scarcity in studies on the Middle East and North Africa (MENA) countries motivates the present paper. In fact, no previous published study has been conducted to investigate the causal relationship between renewable energy and economic growth in the case of Tunisia. The few empirical works that focused on the economic growth-energy consumption nexus in Tunisia dealt essentially with the role played by non-renewable energy (among others, Sebri and Abid, 2012; Abid and Sebri, 2012; Belloumi, 2009). This paper aims at filling this gap by studying the causality linkages between renewable energy consumption and economic growth, controlling for CO₂ emissions and domestic investment. The empirical investigation is conducted on annual data covering the period 1971-2010. The newly developed autoregressive distributed lag (ARDL) technique and the Granger causality approach are implemented in order to check the existence of cointegration and short- and long-run causalities, respectively.

The remainder of this paper is organized as follows. Section 2 presents an overview of the situation of the Tunisian renewable energy sector. In Section 3, the empirical methodology and data are presented. The next section is devoted to discuss the empirical results. Finally, Section 5 closes the paper.

2. The renewable energy profile in Tunisia

During the last decades, the situation of the Tunisian energy sector has changed. Starting from the beginning of the 2000s, the energy balance has recorded a continuing deficit due essentially to the sharp rise in the demand for energy. The industry and transport are the largest energy-consuming sectors, with shares reaching 36% and 31% of total final consumption, respectively. As shown in Figure 1(a), total primary energy demand is mainly based on the natural gas and oil components with more than 80% in 2002. Figure 1(b) indicates that the consumption of oil remains by far the most important, followed by biomass and electricity.

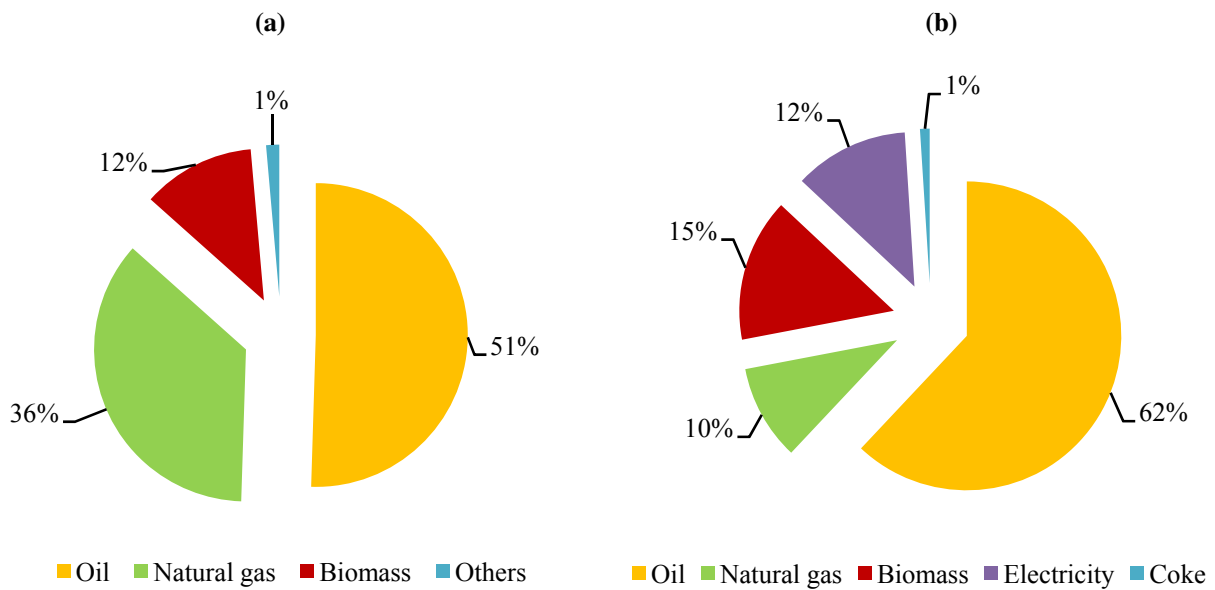


Figure 1. (a) Structure of primary energy demand; (b) Structure of final energy consumption

As a reaction to the growing demand for energy, big share of oil in total energy demand and vulnerability of the economy to crude oil and gas prices, authorities have engaged in implementing policies encouraging energy conservation and promoting renewable energy projects. Another factor that played a significant role is the geographic location of Tunisia. In fact, Tunisia is one of the windiest Mediterranean countries (Boubaker, 2012). Furthermore, the country is characterized by a high solar potential with more than 3200 hours of sunshine per year (Benedetti et al., 2013). The efforts made by the government in order to promote the renewable energies date back to 1985 by the creation of the National Agency of Renewable Energies (NARE) and the National Agency for Energy Conservation (NAEC) in 2004. The main objectives are the promotion of energy efficiency and the set up of renewable and alternative energies.

The International Energy Agency (IEA, 2007) defines six kinds of renewable energy sources: the solar energy, the wind energy, the geothermal energy, the hydropower, the tide/wave and ocean energy and finally the combustible renewable and waste. This latter is especially composed of solid biomass, biogas, liquid biofuels, charcoal and renewable municipal waste.¹ According to the NAEC, one of the first projects implemented in Tunisia is the wind farm launched in 2001 in Sidi Daoud (North-East of Tunisia) with an initial capacity of 10MW, extended to 175MW in 2011. In addition, the Tunisian Solar Plan is an ambitious plan that

¹ For further details on the renewable energy components, see definitions presented in the report 'Renewables in Global Energy Supply' (IEA, 2007 p.23).

envisages the creation of 40 additional wind and solar projects between 2010 and 2016. The cost of the plan is estimated at 2000 million Euros, financed by the private sector (70%), the public sector (22%), the National Energy Conservation Fund (NECF) (7%) and international cooperation (1%). The targeted aim is to reach a level of 16% of the produced electricity based on renewable energies in 2016 and 40% in 2030 (United Nations Economic Commission for Africa, 2012). When all projects installed, the plan will allow saving 660 kilotons of oil equivalent and reducing 1.3 million tons of CO2 emissions per year. In addition, a big international solar energy project, having a capacity up to 2000MW, is currently being prepared in order to install Concentrated Solar Power plants in the South-West of Tunisia. The project aims to export electricity via sub-marine cables (equivalent to pipelines transporting natural gas from Algeria to Italy) to Italy and then it will be distributed to many other European countries.

The public sector, via the Tunisian Company of Electricity and Gas-Renewable Energy (TCEG-RE)² plays a growing role in helping the private sector to launch renewable energy projects by offering technical and financial supports. The TCEG-RE especially helps the large electricity consumers to become self-producers of electricity from renewable energy sources. For example, the company is installing a solar power plant in the biggest oil production concession in Tunisia (El Borma in the South of the country) generating 40MW and a wind power plant in a cement company in the North. In collaboration with the private sector, it is also conducting a feasibility study for the establishment of a biomass power plant producing about 20 MW of electricity using the olive pomace.

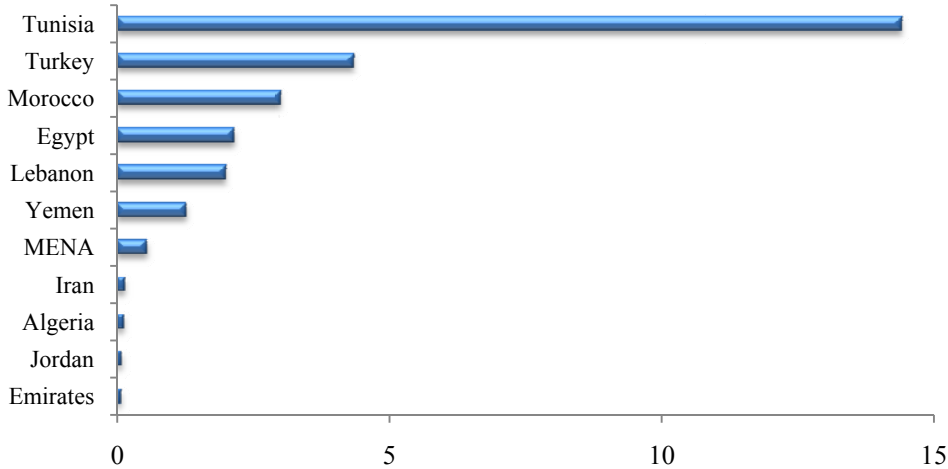


Figure 2. Combustible renewables and waste in selected MENA countries (% of total energy)

² The TCEG-RE is a subsidiary of the Tunisian Company of Electricity and Gas. It has been created in 2010 to promote energy efficiency and renewable energies.

In 2010, combustible renewables and waste represent about 10% of total energy in the world. This kind of renewable energy is particularly used in developing countries. Figure 2 gives an idea about the share of combustible renewables and waste in total energy in some MENA countries in 2010. It is clear that the ratio of combustible renewables and waste to total energy is higher in Tunisia than in other countries. What could be observed is that this ratio is more and more important in oil-importing countries. It is also clear that in oil-exporting countries, such as Iran, Algeria and Emirates, the ratio is weak and is close to zero. Figure 3 describes the evolution of the share of combustible and renewable energy to total energy in Tunisia between 1980 and 2010.

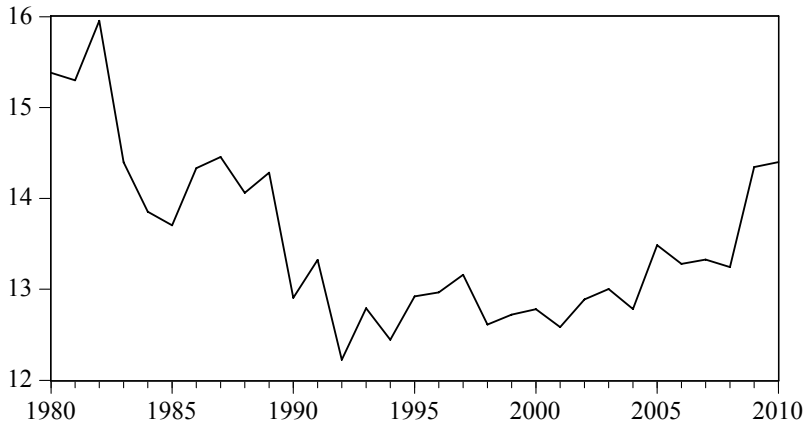


Figure 3. Combustible renewables and waste in Tunisia (% of total energy)

Obviously, the combustible renewables and waste represented about 15% of total energy in early 1980s. The ratio started to fall reaching 12.22% in 1992 and then followed an increasing trend. The rise in the share of combustible renewables and waste in total energy during the last years may be due to the rise of oil prices and the interest given by the government to this kind of renewable energy.

3. Empirical issues

3.1. Data and descriptive statistics

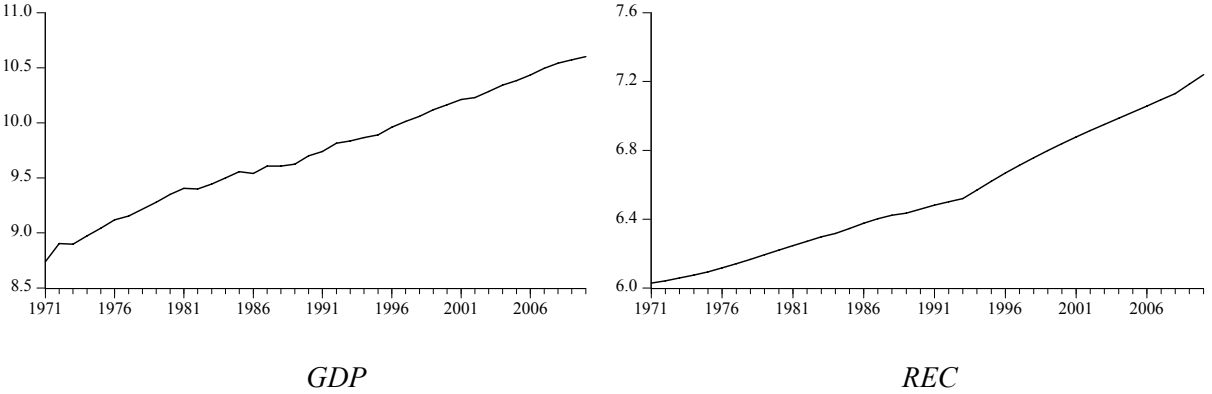
The objective of the study is to investigate the causal relationship between gross domestic product and renewable energy consumption in Tunisia. Given the shortcomings associated with the bivariate causality analysis, we perform a multivariate causality framework by incorporating two additional variables: CO2 emissions and domestic investment

(approximated by the gross capital formation). A substantial empirical literature highlights that dynamic relationships between gross domestic product and CO2 emissions exist (Holtz-Eakin and Selden, 1995; Heil and Selden, 2001). Additionally, CO2 emissions could have causal relationship with renewable energy consumption (Sadorsky, 2009a). According to the economic literature, the second variable, domestic investment, is positively linked to gross domestic product (Barro, 1991). In addition, a share of investment could be allowed to enhance renewable energy projects, which increases the consumption of this kind of energy.

Table 1. Descriptive statistics

| | GDP | REC | CO2 | INV |
|-----------|--------|-------|--------|--------|
| Mean | 9.740 | 6.540 | 9.463 | 8.501 |
| Min. | 8.739 | 6.028 | 8.346 | 7.754 |
| Max | 10.600 | 7.239 | 10.161 | 9.141 |
| Std. dev. | 0.521 | 0.364 | 0.523 | 0.376 |
| Skewness | -0.055 | 0.332 | -0.602 | -0.051 |
| Kurtosis | 1.987 | 1.876 | 2.308 | 2.106 |

The data are annual and spans the time period 1971 to 2010. Real gross domestic product (GDP) and domestic investment (INV) are expressed in millions of constant 2005 US dollars; CO2 emissions (CO2) is expressed in kilotons; renewable energy consumption (REC) is proxied by the combustible renewables and waste (in metric tons of oil equivalent). All the variables are extracted from the World Development Indicators (WDI) produced by the World Bank and are expressed in natural logarithm. In Table 1, we present some descriptive statistics.



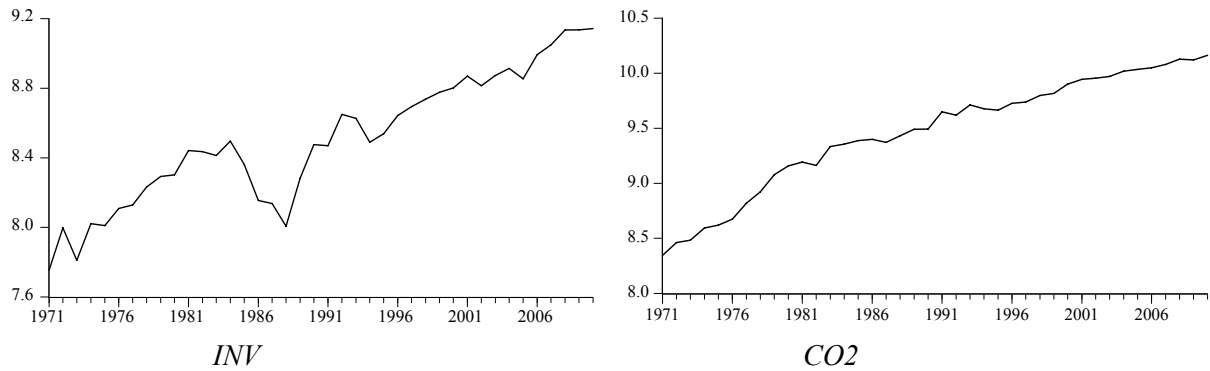


Figure 4. Plots of the variables

Figure 1 illustrates the evolution of variables over the period 1971-2010. It indicates a continuous increasing trend in real national income, the renewable energy consumption and the CO2 emissions. With regard to the domestic investment, it has increased over time, but with a sharp decrease in the mid-1980s, a period in which the Tunisian economy experienced a financial and economic crisis.

3.2. *The empirical strategy*

The present study employs the ARDL bounds testing approach introduced by Pesaran and Shin (1999) and developed by Pesaran et al. (2001) in order to assess the causality relationship between economic growth and renewable energy consumption. As pointed out by many authors, this approach presents several advantages compared to conventional cointegration methods (Jalil and Feridun, 2011; Ben Salha, 2013). Among others, it allows testing the existence of cointegration relationships even in the presence of variables characterized by different integration orders.³ In addition, Odhiambo (2009) points out that the ARDL cointegration approach gives unbiased estimates of the long-run relationship, even if some variables introduced in the regression are endogenous. Finally, Kumar and Pacheco (2012) advance that the ARDL technique simultaneously estimates the short- and long-run coefficients, which avoids the problems of autocorrelation and omitted variables.

Our empirical strategy involves a four-stage procedure. First, we start by applying the weighted symmetric ADF unit root test (ADF-WS) developed by Park and Fuller (1995). This test has good power properties and size when compared to conventional unit root tests (Leybourne et al., 2005). Second, the existence of long-run relationship is investigated based

³ It is crucial to ensure that none of the variables is integrated of order two or above. The implementation of the ARDL cointegration approach is not possible in this case.

on the F -test. The following ARDL models are estimated using Sebri and Ben Salha (2013) notations:

$$\begin{aligned} \Delta GDP_t = & a_{10} + \sum_{i=1}^{k1} \alpha_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{l1} \beta_{1i} \Delta REC_{t-i} + \sum_{i=0}^{m1} \gamma_{1i} \Delta CO2_{t-i} + \sum_{i=0}^{n1} \lambda_{1i} \Delta INV_{t-i} \\ & + \phi_{11} GDP_{t-1} + \phi_{12} REC_{t-1} + \phi_{13} CO2_{t-1} + \phi_{14} INV_{t-1} + \varepsilon_{1t} \end{aligned} \quad (1)$$

$$\begin{aligned} \Delta REC_t = & a_{20} + \sum_{i=0}^{k2} \alpha_{2i} \Delta GDP_{t-i} + \sum_{i=1}^{l2} \beta_{2i} \Delta REC_{t-i} + \sum_{i=0}^{m2} \gamma_{2i} \Delta CO2_{t-i} + \sum_{i=0}^{n2} \lambda_{2i} \Delta INV_{t-i} \\ & + \phi_{21} GDP_{t-1} + \phi_{22} REC_{t-1} + \phi_{23} CO2_{t-1} + \phi_{24} INV_{t-1} + \varepsilon_{2t} \end{aligned} \quad (2)$$

$$\begin{aligned} \Delta CO2_t = & a_{30} + \sum_{i=0}^{k3} \alpha_{3i} \Delta GDP_{t-i} + \sum_{i=0}^{l3} \beta_{3i} \Delta REC_{t-i} + \sum_{i=1}^{m3} \gamma_{3i} \Delta CO2_{t-i} + \sum_{i=0}^{n3} \lambda_{3i} \Delta INV_{t-i} \\ & + \phi_{31} GDP_{t-1} + \phi_{32} REC_{t-1} + \phi_{33} CO2_{t-1} + \phi_{34} INV_{t-1} + \varepsilon_{3t} \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta INV_t = & a_{40} + \sum_{i=0}^{k4} \alpha_{4i} \Delta GDP_{t-i} + \sum_{i=0}^{l4} \beta_{4i} \Delta REC_{t-i} + \sum_{i=0}^{m4} \gamma_{4i} \Delta CO2_{t-i} + \sum_{i=1}^{n4} \lambda_{4i} \Delta INV_{t-i} \\ & + \phi_{41} GDP_{t-1} + \phi_{42} REC_{t-1} + \phi_{43} CO2_{t-1} + \phi_{44} INV_{t-1} + \varepsilon_{4t} \end{aligned} \quad (4)$$

Where Δ is the first difference operator; $a_{j0}, \alpha_j, \beta_j, \gamma_j, \lambda_j$ and ϕ_{jj} ($j = 1, \dots, 4$) are parameters to be estimated; k_j, l_j, m_j and n_j ($j = 1, \dots, 4$) are the optimal lag length selected using the Schwarz Bayesian Criterion (SBC). Finally, ε_{jt} ($j = 1, \dots, 4$) are white noise error terms.

The null hypothesis of having no cointegration $H_0 : \phi_{j1} = \phi_{j2} = \phi_{j3} = \phi_{j4} = 0$ is tested against the alternative hypothesis $H_1 : \phi_{j1} \neq \phi_{j2} \neq \phi_{j3} \neq \phi_{j4} \neq 0$ ($j = 1, \dots, 4$). The computed F -statistics are then compared to the lower bound and upper bound critical values. According to Narayan and Narayan (2005), the lower and upper bounds critical values depend on three main criteria: (i) The inclusion of only an intercept or an intercept and a time trend in the regression; (ii) The integration order of variables; and (iii) The number of explanatory variables.

Once cointegrating relationships exist, the next stage involves estimating the long-run and short-run coefficients. In the present study, the long-run coefficients are computed using the ARDL estimates and the Dynamic Ordinary Least Squares (DOLS) developed by Stock and Watson (1993). This latter avoids problems related to small sample bias and simultaneity. Since the existence of long-run relationships means that there must be Granger causality in at

least one direction, a causality test should be implemented. Consequently, the final step consists in assessing the direction of short- and long-run causalities. To do so, the following error correction-models are estimated using Sebri and Ben Salha (2013) notations:

$$\begin{aligned} \Delta GDP_t = & b_{10} + \sum_{i=1}^{p1} \theta_{1i} \Delta GDP_{t-i} + \sum_{i=1}^{q1} \phi_{1i} \Delta REC_{t-i} + \sum_{i=1}^{r1} \delta_{1i} \Delta INV_{t-i} \\ & + \sum_{i=1}^{s1} \omega_{1i} \Delta CO2_{t-i} + \psi_1 ECT_{t-1} + \xi_{1t} \end{aligned} \quad (5)$$

$$\begin{aligned} \Delta REC_t = & b_{20} + \sum_{i=1}^{p2} \theta_{2i} \Delta GDP_{t-i} + \sum_{i=1}^{q2} \phi_{2i} \Delta REC_{t-i} + \sum_{i=1}^{r2} \delta_{2i} \Delta INV_{t-i} \\ & + \sum_{i=1}^{s2} \omega_{2i} \Delta CO2_{t-i} + \psi_2 ECT_{t-1} + \xi_{2t} \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta CO2_t = & b_{30} + \sum_{i=1}^{p3} \theta_{3i} \Delta GDP_{t-i} + \sum_{i=1}^{q3} \phi_{3i} \Delta REC_{t-i} + \sum_{i=1}^{r3} \delta_{3i} \Delta INV_{t-i} \\ & + \sum_{i=1}^{s3} \omega_{3i} \Delta CO2_{t-i} + \psi_3 ECT_{t-1} + \xi_{3t} \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta INV_t = & b_{40} + \sum_{i=1}^{p4} \theta_{4i} \Delta GDP_{t-i} + \sum_{i=1}^{q4} \phi_{4i} \Delta REC_{t-i} + \sum_{i=1}^{r4} \delta_{4i} \Delta INV_{t-i} \\ & + \sum_{i=1}^{s4} \omega_{4i} \Delta CO2_{t-i} + \psi_4 ECT_{t-1} + \xi_{4t} \end{aligned} \quad (8)$$

Where $b_{j0}, \theta_j, \phi_j, \delta_j, \omega_j$ ($j=1, \dots, 4$) are parameters to be estimated; ξ_{jt} ($j=1, \dots, 4$) are white noise error terms; ECT is the error correction term. Finally, the coefficients ψ_j ($j=1, \dots, 4$) of the $ECTs$ measures the speed of adjustment to obtain the long-run equilibrium in the event of shocks to the system.

To assess the goodness of fit of the estimated ARDL models, several tests are implemented, that is, the Jarque Bera normality test, the ARCH test for heteroscedasticity, the Breusch–Godfrey serial correlation LM test and the Ramsey RESET test for model specification.

4. Empirical results

4.1. Integration and cointegration analyses

We start the empirical investigation of the dynamic linkages between renewable energy consumption, CO2 emissions, domestic investment and economic growth by testing the stationary properties of times series. Table 2 presents the results of the ADF-WS unit root test with an intercept and with and intercept and a time trend. We also report the simulated critical values at 5% and 10% levels.

Table 2. ADF-WS unit root test

| Variable | At level | | At first difference | | |
|-----------------|-------------|---------------------|---------------------|---------------------|------------|
| | Intercept | Intercept and trend | Intercept | Intercept and trend | |
| GDP | 3.645 (0)** | -1.693 (1) | -4.260 (1)** | -4.489 (1)** | |
| REC | 3.633 (0)** | 1.182 (0) | -1.258 (1) | -3.058(1)* | |
| CO2 | 2.508 (0)* | -0.573 (0) | -7.072 (0)** | -4.505 (1)** | |
| GCF | 0.617 (1) | -2.597 (1) | -4.258 (1)** | -4.204 (1)** | |
| Critical values | 5% | -2.553 (0) | -3.456 (0) | -2.486 (0) | -3.243 (0) |
| | | -2.600 (1) | -3.555 (1) | -2.607 (1) | -3.416 (1) |
| | 10% | -2.238 (0) | -3.028 (0) | -2.271 (0) | -2.954 (0) |
| | | -2.305 (1) | -3.105 (1) | -2.259 (1) | -3.042 (1) |

Notes: Critical values for variables in level are simulated using 38 observations and 1000 replications. For variables in first difference, critical values are simulated using 37 observations and 1000 replications. Values in parentheses indicate the lag length. ** and * illustrate the statistical significance at 5% and 10% levels, respectively.

As it is shown, the ADF-WS unit root test indicates that the real gross domestic product and the renewable energy consumption are integrated of order zero or order one. Specifications including either an intercept or an intercept and a time trend give mixed results. The most important issue is that none of the two variables is integrated of order two or above. Results associated with CO2 emissions and domestic investment suggest that they are integrated of order one. These findings imply that the ARDL bounds testing approach to cointegration is appropriate to estimate the existence of long-run relationships. The Johansen and Juselius (1990) cointegration technique is not recommended in our case since some variables are not integrated of order one.

Table 3 presents the computed F -statistics for the existence of cointegrating relationships and the associated validation tests. The Panel A of Table 3 shows that the F -statistics are higher than the upper critical bounds when the real gross domestic product and the renewable energy consumption are the dependant variables. Consequently, two long-run cointegrating relationships between real GDP and its determinants and between renewable energy consumption and its determinants exist.

Table 3. Bounds F -test for cointegration and associated diagnostic tests

| <i>Panel A: Bounds testing for cointegration</i> | | | | | | | | |
|---|-----------------|-----------------------|--------|---------------|--------|-----------------|--------|------------------|
| Model | F -statistic | Critical value bounds | | | | | | Decision |
| | | 10% | | 5% | | 1% | | |
| | | $I(0)$ | $I(1)$ | $I(0)$ | $I(1)$ | $I(0)$ | $I(1)$ | |
| $F_{GDP}(GDP REC,CO2,GCF)$ | 6.976*** | 2.933 | 4.020 | 3.548 | 4.803 | 5.018 | 6.610 | Cointegration |
| $F_{REC}(REC GDP,CO2,GCF)$ | 11.389*** | 2.933 | 4.020 | 3.548 | 4.803 | 5.018 | 6.610 | Cointegration |
| $F_{CO2}(CO2 GDP,REC,GCF)$ | 3.016 | 2.933 | 4.020 | 3.548 | 4.803 | 5.018 | 6.610 | Inconclusive |
| $F_{GCF}(GCF GDP,REC,CO2)$ | 2.607 | 2.933 | 4.020 | 3.548 | 4.803 | 5.018 | 6.610 | No cointegration |
| <i>Panel B: Diagnostic tests of the underlying ARDL model</i> | | | | | | | | |
| | χ^2 normal | χ^2 reset | | χ^2 arch | | χ^2 serial | | |
| $GDP=f(REC,CO2,GCF)$ | 0.110 (0.946) | 1.170 (0.279) | | 3.386 (0.066) | | 0.360 (0.548) | | |
| $REC=f(GDP,CO2,GCF)$ | 0.610 (0.737) | 1.859 (0.173) | | 2.151 (0.142) | | 11.885 (0.001) | | |
| $CO2=f(GDP,REC,GCF)$ | 1.090 (0.580) | 5.892 (0.015) | | 1.599 (0.206) | | 4.173 (0.041) | | |
| $GCF=f(GDP,REC,CO2)$ | 0.431 (0.806) | 1.227 (0.268) | | 5.289 (0.021) | | 1.155 (0.282) | | |

Notes: The Schwarz information criterion is used to select the optimal lag length for the ARDL model. The critical values are obtained from Narayan (2005). *** denotes the presence of cointegration at the significance level of 1%.

When the CO2 emissions is treated as the dependant variable, the F -statistic lies between the lower and the upper bounds, which implies that no conclusion on the existence on a long-run relationship could be advanced. Finally, the results show that there is no cointegration between domestic investment and its determinants, given that the F -statistic is below the lower bound critical values. The economic theory suggests that other determinants may explain more the level of domestic investment in the long-run. According to Panel B of the same table, it is clear that the four ARDL models generally pass the computed diagnostic tests.

4.2. Long-run and short-run estimates

The next stage of the analysis consists in estimating the long- and short-run coefficients associated with models for which cointegrating relationships exist, i.e. when real GDP and renewable energy consumption are treated as dependant variables. In addition, we also compute such coefficients when CO2 emissions are the dependant variable, even if no conclusive decision on the existence of cointegration is found. Bahmani-Oskooee and Rehman (2005) advance that the computed F -statistic presents a preliminary conclusion on the existence of long-run relationship. They state also that the lagged error correction term is a more powerful tool. In Table 4, we present in Panel A the estimated long-run coefficients using the ARDL modeling and the DOLS technique, while Panel B focuses on the error-correction models.

Table 4. Long-run and short-run analyses

| Panel A : Long-run coefficients | | | | |
|--|-----------------------|----------------|-----------------------|----------------|
| | <i>ARDL estimates</i> | | <i>DOLS estimates</i> | |
| | coefficient | p-value | coefficient | p-value |
| <i>Dependant variable: GDP</i> | | | | |
| <i>REC</i> | 0.831 ^{***} | 0.000 | 0.838 ^{***} | 0.000 |
| <i>CO2</i> | 0.343 ^{***} | 0.000 | 0.379 ^{***} | 0.000 |
| <i>GCF</i> | 0.098 [*] | 0.062 | 0.044 | 0.392 |
| <i>constant</i> | 0.247 | 0.102 | 0.289 [*] | 0.099 |
| <i>Dependant variable: REC</i> | | | | |
| <i>GDP</i> | 1.343 ^{***} | 0.000 | 1.175 ^{***} | 0.000 |
| <i>CO2</i> | -0.543 ^{***} | 0.001 | -0.437 ^{***} | 0.000 |
| <i>GCF</i> | 0.084 | 0.573 | -0.053 | 0.366 |
| <i>constant</i> | -1.807 [*] | 0.061 | -0.313 ^{**} | 0.047 |
| <i>Dependant variable: CO2</i> | | | | |
| <i>GDP</i> | 2.162 ^{***} | 0.000 | 2.422 ^{***} | 0.000 |
| <i>REC</i> | -1.729 ^{***} | 0.000 | -2.033 ^{***} | 0.000 |
| <i>GCF</i> | -0.021 | 0.894 | 0.011 | 0.902 |
| <i>constant</i> | -0.058 | 0.899 | -0.855 ^{**} | 0.022 |
| Panel B: Short-run coefficients | | | | |
| | coefficient | p-value | | |
| <i>Dependant variable: ΔGDP</i> | | | | |
| <i>ΔREC</i> | 0.466 ^{***} | 0.000 | | |
| <i>ΔCO2</i> | 0.192 ^{***} | 0.001 | | |
| <i>Δ GCF</i> | 0.129 ^{***} | 0.000 | | |
| <i>ecm_{t-1}</i> | -0.561 ^{***} | 0.000 | | |
| <i>Dependant variable: ΔREC</i> | | | | |
| <i>ΔGDP</i> | 0.123 ^{**} | 0.030 | | |
| <i>ΔCO2</i> | -0.050 ^{**} | 0.029 | | |
| <i>Δ GCF</i> | -0.020 | 0.137 | | |
| <i>ecm_{t-1}</i> | -0.092 [*] | 0.058 | | |
| <i>Dependant variable: ΔCO2</i> | | | | |
| <i>ΔGDP</i> | 0.970 ^{**} | 0.012 | | |
| <i>ΔREC</i> | -0.775 ^{**} | 0.015 | | |
| <i>Δ GCF</i> | -0.009 | 0.896 | | |
| <i>ecm_{t-1}</i> | -0.448 ^{***} | 0.002 | | |

Note: ^{***}, ^{**} and ^{*} denote the statistical significance at the 1%, 5% and 10% levels, respectively.

The two methods used to estimate the long-run coefficients almost provide similar findings, confirming the robustness of results. A first look at the findings shows that independent variables have the expected signs in the three models. To start, it has been revealed that the renewable energy consumption and CO2 emissions positively impact the real GDP at the 1% significance level, whether the ARDL or the DOLS method is used. Regarding the domestic investment, it shows a positive and statistically significant coefficient only under the ARDL estimates. The same table reveals that renewable energy consumption is positively (negatively) affected by real GDP (CO2 emissions). More CO2 emissions imply more consumption of fuel and other non-renewable energy, which may negatively affect the

consumption of renewable energy. When the CO₂ emissions variable is set as dependant variable, the real GDP presents a positive and statistically significant coefficient, contrarily to the renewable energy consumption. In Tunisia, about one third of GDP comes from the industrial sector. That is, the development of industrial activities automatically raises the level of CO₂ emissions. Finally, renewable energy consumption induces a fall in CO₂ emissions in the long-run, since it is a clean source of energy compared to non-renewable energy the primary source of CO₂ emissions.

The short-run adjustments are investigated in Panel B of Table 4. Results associated with real GDP and CO₂ emissions are similar to those found in the long-run. As for the renewable energy consumption, it is only affected by real GDP. Two main statements may also be advanced. First, the short-run coefficients are lower than those of the long-run, notably for the renewable energy consumption model. This means that shocks to variables tend to be aggravated by the short-run dynamics. The second point is related to the error correction terms. All of them are negative and statistically significant, which corroborates results of the *F*-statistics derived from the cointegration analysis and indicates that the three variables cannot diverge systematically from a long-run equilibrium position. This term, capturing the extent to which the deviation from the long-run equilibrium is corrected through partial short-run adjustments, is found to be higher for the GDP model. On the contrary, the renewable energy consumption model presents the lowest error-correction term. Only 9.2% of the disequilibria in the renewable energy consumption due to previous shocks adjust back to the long-run equilibrium in the current year.

4.3. Causality

The subsequent analysis consists in investigating the causal nexus between the competing variables. The dynamic causal relationships between real GDP, renewable energy consumption, CO₂ emissions and domestic investment are tested using the error-correction model. This allows assessing the causality links based on the *F*-statistics of the lagged first-differences of explanatory variables (short-run causality) and the *t*-statistics of the error-correction term (long-run causality). Finally, the joint *F*-statistics test whether the two sources of causality are jointly significant. Results of the Granger causality test are summarized in Table 5.

Table 5. VECM Granger causality analysis

| Dep. variable | Short-run | | | | Long-run | Joint |
|---------------|--------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| | F-statistics | | | | t-statistics | F-statistics |
| | (p-value) | | | | (p-value) | (p-value) |
| | ΔGDP | ΔREC | ΔCO_2 | ΔGCF | ECT_{t-1} | |
| ΔGDP | - | 22.835*** (0.000) | 13.650*** (0.001) | 15.522*** (0.000) | -4.898*** (0.000) | 18.693*** (0.000) |
| ΔREC | 5.134** (0.030) | - | 5.202** (0.029) | 2.323 (0.137) | -1.960* (0.058) | 15.382*** (0.000) |
| ΔCO_2 | 7.134** (0.012) | 6.634** (0.015) | - | 0.017 (0.896) | -3.329*** (0.002) | 5.272*** (0.000) |

Note: ***, ** and * denote the statistical significance at the 1%, 5% and 10% levels, respectively.

In the short-run, results indicate that the renewable energy consumption, CO₂ emissions and the domestic investment cause real GDP, which corroborates previous results drawn from Table 4. At the same time, only real GDP and CO₂ emissions present significant coefficients at 5% level in the renewable energy consumption error-correction model. Thus, in the short-run, the increase in economic growth and CO₂ emissions plays a significant role in the consumption of renewable energy. Economic growth allows financing new projects, while CO₂ emissions and the degradation of the environmental situation incite policymakers to launch new renewable energy projects, which raises the production and the consumption of such kind of energy. Finally, there is a short-run causality running from economic growth and renewable energy consumption to CO₂ emissions. These findings confirm those found in Panel B of Table 4, suggesting that economic growth and renewable energy consumption exert positive and negative effects on CO₂ emissions, respectively. The promotion of renewable energy in developing countries such as Tunisia may reduce the use of non-renewable energy consumption. As pointed out previously, some large energy consumers companies in Tunisia have implemented renewable energy projects in order to generate electricity, which normally reduces the emissions of CO₂. Besides, the Tunisian Solar Plan, presented above, aims to reduce the CO₂ emissions by about 1.3 million tons per year.

In the long-run, all *t*-statistics associated with the *ECTs* confirm the existence of a causal relationship among the variables. Even if the error-correction term associated with renewable energy consumption is statistically significant only at 10% level, results are in line with those found in the short-run. Finally, the joint *F*-test indicates the existence of bi-directional causality between GDP and renewable energy consumption, since the null hypothesis, stating

that the coefficients on the associated *ECTs* and lagged first-differences are jointly zero in both the GDP equation and the REC equation, is rejected at 1% level. To summarize, the main finding that emerge from the causality analysis is the presence of bi-directional causality between real GDP and renewable energy consumption, supporting therefore the feedback hypothesis.

4.4. Controlling for structural change

Despite that the findings suggest that long-run relationships between renewable energy consumption and economic growth exist, it is important to test the presence of structural change before addressing policy implications. As advanced by Égert et al. (2006), structural change in macroeconomic data often corresponds to the instability in the real economy. In addition, many authors outline that not taking into account the presence of structural break may induce biased results (among others Pahlavani, 2005 and Perron, 1997). Therefore, to check the presence of structural break, we use two tests: the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) tests developed by Brown et al. (1975) and the Zivot-Andrews unit root test (Zivot and Andrews, 1992) with one structural break.

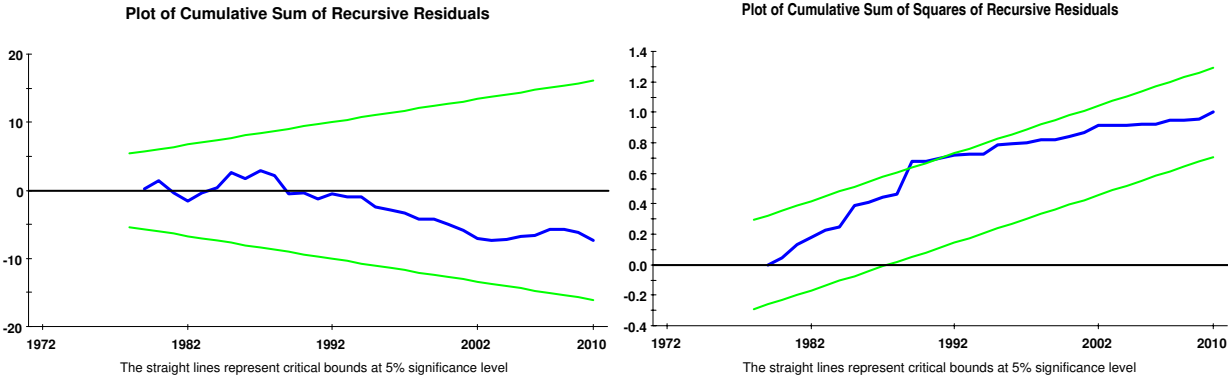


Figure 5. Plots of CUSUM and CUSUMSQ tests

As shown in Figure 5, the CUSUM test suggests the stability of the estimated parameters associated with the GDP model during the considered period. On the contrary, the CUSUMSQ moves outside the 5% critical bounds, suggesting the existence of structural break in the growth model estimation. According to the graph inspection, a structural change occurred in the end of the 1980s. However, one could not make a decision based only on the

graph. The exact time break at which the structural change occurred is detected using the Zivot-Andrews unit root test.

Table 6. Zivot-Andrews structural break unit root test

| Variable | At level | | | | At first difference | | | |
|----------|---------------|-----------------|-----------------|-----------------|---------------------|-----------------|-----------------|-----------------|
| | <i>Int.</i> | <i>T. break</i> | <i>Int.+tr.</i> | <i>T. break</i> | <i>Int.</i> | <i>T. break</i> | <i>Int.+tr.</i> | <i>T. break</i> |
| GDP | -3.701(1) | 1986 | -3.647(1) | 1986 | -11.714(0)*** | 1982 | -11.549(0)*** | 1990 |
| REC | -1.437(1) | 1983 | -4.892(1)* | 1991 | -4.846(0)* | 1994 | -4.830(0)* | 1994 |
| CO2 | -6.834(11)*** | 2000 | -7.432(11)*** | 2004 | -9.046(0)*** | 1981 | -10.051(0)*** | 1981 |
| GCF | -5.064(0)** | 1985 | -5.052(0)* | 1985 | -8.686(0)*** | 1989 | -8.906(0)*** | 1989 |

Note: ***, ** and * denote the statistical significance at the 1%, 5% and 10% levels, respectively.

As reported in the Table 6, the Zivot-Andrews unit root test shows that all variables are integrated of order zero or order one, confirming those of the ADF-WS unit root test. The most interesting result is the detected time break associated with real GDP. Whether an intercept or an intercept and a time trend are included, the test suggests that the structural break occurred in 1986. In fact, a disastrous economic, financial and social crisis occurred in Tunisia during this period, which exerted harmful effects on the economic activity and on the macroeconomic situation. As a result, the country adopted the Structural Adjustment Program, initiated essentially by the International Monetary Fund (IMF). The date of the structural break associated with GDP is also confirmed by the one associated with the domestic investment variable (1985) since a fall in domestic investment coincides in time with a fall in the economic activity.

Following Ozturk and Acaravci (2011), we include a dummy variable corresponding to 1986 in order to control for structural break and we reconduct again the cointegration and causality analyses. Results of the long-run relationships are almost similar to those found previously in Table 3. The *F*-statistics associated with real GDP and renewable energy consumption are higher than the upper bounds critical values, which confirms the existence of long-run relationships. Contrariwise, the ARDL bounds testing approach shows that no cointegration exists when the CO2 emissions and domestic investment are set as dependant variables.⁴ Consequently, only two error-correction models are considered when investigating the short- and long-run causal relationships. It emerges from the Granger causality test that there is bi-

⁴ Findings reported in Table 3 indicate that no conclusive decision on the existence of cointegration relationships may be advanced. The inclusion of the dummy variable confirms that CO2 emissions, renewable energy consumption, real GDP and domestic investment are not cointegrated.

directional causality between renewable energy consumption and real GDP in both the short- and the long-run. These results are in line with those found before including the dummy variable in the analysis. Therefore, the structural break occurred in 1986 does not significantly affected the interactions between renewable energy consumption and real GDP. Each variable seems to cause the other one in both the short- and long-run. The feedback hypothesis between economic growth and renewable energy consumption is consistent, even if we take into consideration shocks that occurred to the country.

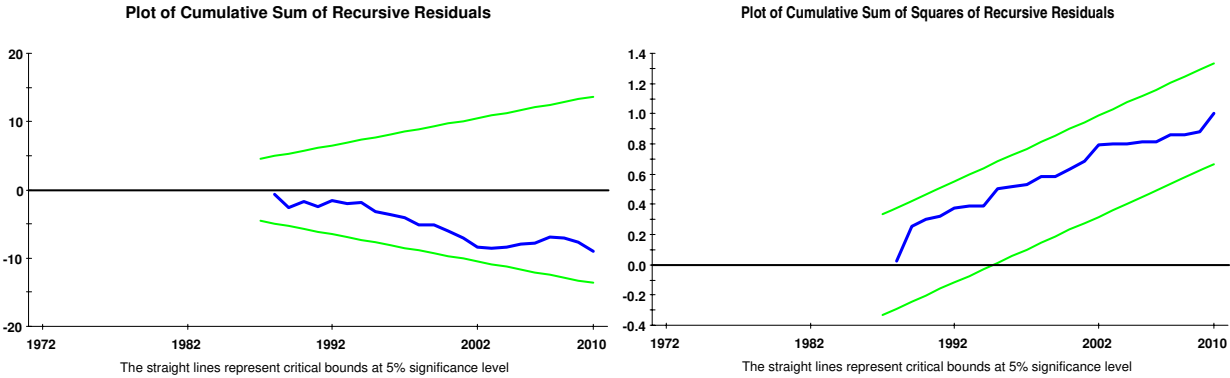


Figure 6. Plots of CUSUM and CUSUMQ tests based on the ARDL model with dummy variable

As in the baseline analysis, we plot the graphs of the CUSUM and CUSUMSQ in order to check if the inclusion of the dummy variable resolves the issue of the presence of structural change. Figure 6 suggests that there is no structural change in the GDP model, since the CUSUM and CUSUMSQ statistics move within the 5% critical bounds.

5. Concluding remarks

Although the relationship between economic growth and non-renewable energy consumption is a well documented topic in the literature, the one linking economic growth to renewable energy consumption has not been sufficiently discussed. This may be partly due to the fact that the use of this kind of energy has only increased in the last years. The empirical literature essentially focused on countries from Asia, Latin America and Europe. Works on African countries are relatively scarce. The aim of this paper is to fill this gap by shedding light on the causality linkages between economic growth, renewable energy consumption, CO2 emissions

and domestic investment in Tunisia. To do so, data ranging between 1971 and 2010 has been used and the ARDL bounds testing approach to cointegration and the Granger causality test have been implemented.

In the light of the empirical investigation, we divulge that there is bi-directional causality between economic growth and renewable energy consumption. In addition, this causal relationship exists in both the short- and long-run. These findings confirm the validity of the feedback hypothesis in Tunisia. That is, more renewable energy consumption leads to more economic growth via the use of energy in the economic activity while a rise in economic growth leads to higher demand of renewable energy. The impact of economic growth on renewable energy consumption may be transmitted via financing the renewable energy projects. The Granger causality test reveals also that bi-directional causality exists between CO₂ emissions and economic growth on the one hand, and between CO₂ emissions and renewable energy consumption on the other hand. The estimation of long-run coefficients indicates that CO₂ emissions exert positive and negative effects on economic growth and on the consumption of renewable energy, respectively. Similarly, economic growth and (renewable energy consumption) rises (decreases) CO₂ emissions. These results are of great policy importance since the consumption of renewable energy allows enhancing economic growth and at the same time, it reduces the emissions of polluting CO₂ emissions.

We finish the empirical investigation by testing the presence of structural change. The CUSUMSQ test and the Zivot-Andrews structural break unit root test indicate that a structural break occurred in 1986, a year at which the Tunisian economy experienced a deep financial and economic crisis. Thus, we replicate the same procedure by including a dummy variable corresponding to the structural break date. Results confirm those of the baseline analysis since there is bi-directional causality between economic growth and renewable energy consumption in both the short- and long-run, validating therefore the feedback hypothesis.

Finally, it is worth noting that the renewable energy is a promoting sector in Tunisia. It is not only an engine of economic growth, but it helps also to alleviate the global warming pressure by reducing the CO₂ emissions. Nevertheless, more financial resources, international cooperation and institutional encouragements should be allocated to further develop this sector.

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