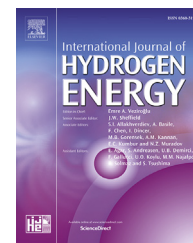


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# An ARDL approach to the CO<sub>2</sub> emissions, renewable energy and economic growth nexus: Tunisian evidence

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## ABSTRACT

This paper examines the relationship between CO<sub>2</sub> emissions, renewable energy consumption (RENEC) and economic growth in Tunisia via an Autoregressive Distributed Lag model. Our research question is to what extent renewable energies can be used as an alternative to conventional energies, which are very well known by their strong emissions of greenhouse gases. We use Granger causality tests to check the short and long-run equilibrium relationship. Furthermore, we try to determine the causality direction between these three variables for the Tunisian economy. The results reveal that for the gross domestic product (GDP), CO<sub>2</sub> emissions and RENEK are stable in the long-term. However, the Granger causality tests indicate a bidirectional relationship between GDP and CO<sub>2</sub> emissions as well as between RENEK and GDP but no relationship between CO<sub>2</sub> emissions and RENEK. Thus, to succeed an energy transition project and to benefit from positive impacts on economic growth and environment protection, an appropriate strategy encouraging renewable energy use should be adopted.

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## Introduction

Recent research has recently shifted focus to whether development of renewable energy sources is a strategic plan to maintain energy security and reduce carbon emissions. The challenge is how to protect the environment for future generations. As reported by Ref. [1], actually almost 81% of all primary energy sources worldwide is derived from fossil fuels, with oil accounting for 31.1%, coal for 28.9% and natural gas for 21.4%. Then, energy is the main source of greenhouse gas

emissions (GHG), but it is also necessary for economic production and, therefore, economic growth and the development of society. For this reason, many researchers have focused recently on the vital role of renewable energy in reducing energy-induced GHG.

In Tunisia, a large amount of energy is being consumed for economic purposes. Almost 97% of the total primary energy consumption in the country depends on oil and gas, emitting more CO<sub>2</sub> into the environment. These pollutant emissions reached 30379 ktCO<sub>2</sub> in 2013 compared to 22000 ktCO<sub>2</sub> in 2000 because of this amount of energy consumption. Therefore,

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energy consumption can be considered the main cause of environment pollution in Tunisia. However, during the last decades, Tunisia has been trying to implement different energy scenarios and strategies to resolve energy and environmental problems and to develop renewable energy alternatives. Development and use of renewable energy technologies should reduce carbon emissions and enhance sustainable growth. Renewable energies come from different sources like wind, the sun, biomass, etc. They are considered reliable and clean, compared to conventional energy sources, in particular fossil fuels.

In the literature, we distinguish different relationships between renewable energy consumption, economic growth, CO<sub>2</sub> emissions and other variables. This bulk of research used a number of empirical approaches like the ARDL testing bound approach or the Granger causality test. The results seem to depend on the sample chosen, the variables used in the analysis and the study period (see Ref. [2] for a review of recent studies).

For example [3], examined the relationship between renewable energy and economic growth in the long-run by applying a test developed by Ref. [4] over 80 countries belonging to four world regions. They found bidirectional causality between renewable energy consumption and GDP in the long-run across all regions. Comparing 31 OECD and 49 non-OECD countries [2], studied the long-run causal relationship between renewable energy consumption and economic growth between 1990 and 2010. Their results reveal the validity of the conservation hypothesis between the two variables for developed countries but the feedback hypothesis for less-developed countries. The authors conclude that renewable energies play an important role in economic growth for non OECD countries and not for OECD countries.

Growing interest has been attributed to renewable energy as a solution to reduction of emissions of greenhouse gases. Energy strategy in many countries is towards promotion of renewable energy and the legislative and regulatory framework adopted in these countries during last years confirm this commitment as in Tunisia and Algeria ([5,6]).

In a recent work [7], examined the renewable energy transition in Tunisia within a nonlinear and unstable context. They tried to assess the role which could be played by renewable energy for a sustainable growth in Tunisia regarding the local structure transformation after the revolution. In their work, they applied the univariate STAR model over the 1990–2013 sample period to examine both nonlinearity and endogenous structural change. The main variable used in their econometric analysis is total renewable energy production composed by wind, hydro and solar photovoltaic. Their results prove that the transition to renewable energy in tunisian case is possible but smoothly.

Moreover, by exploring the long-run causal relationship between renewable energy consumption, CO<sub>2</sub> emissions, labor, capital and economic growth for Jordan during 1986–2012 [8], found a bidirectional relationship between these variables, except for labor. The author concludes that renewable energy reduces CO<sub>2</sub> emissions. Using the ARDL bounding test method [9], examined the relationship between Japanese renewable energy capacity and economic growth

and concluded that the first stimulate the latter but the government still prefers nuclear power generation. On the other hand, recent studies of the relationship between economic growth and renewable energy consumption targeted the Tunisian case ([10,11]).

[10] used the ARDL approach and the Granger causality test to study the short and long-run relationships between health indicator, real GDP, combustible renewable and waste consumption, rail transport, and CO<sub>2</sub> emissions in Tunisia during 1990–2011. The author pointed to the benefits of using renewable energy as an alternative to reduce pollution and improve public health. Besides, in their paper [11], examined the causality relationships between economic growth, renewable energy consumption, CO<sub>2</sub> emissions and domestic investment in Tunisia during 1971–2010, using the ARDL bounding test approach. They confirm the feedback hypothesis between renewable energy consumption and economic growth in the country as their results reveal a bidirectional relationship between the two variables.

Our contribution to the previous studies is to study the dynamic interaction between CO<sub>2</sub> emissions, economic growth and renewable energy consumption in Tunisia by considering the post-revolution period. Then, our study period stretches from 1990 to 2015. The purpose of this study is to answer the following three questions:

Is economic growth positively affected by the use of renewable energy?

Do CO<sub>2</sub> emissions decrease by the use of renewable energy?

Do CO<sub>2</sub> emissions depend on economic growth?

To this end, the autoregressive distributed lag (ARDL) technique and the Granger causality approach are used in order to explore the existence of cointegration and short and long-run causality, respectively. Ultimately, our results can provide evidence for policy makers to whether promote or not renewable energy use and to limit non-renewable energy. This paper is then structured as follows.

The Section [Energy context in Tunisia](#) presents a brief overview of energy context in Tunisia; Section [Methodology](#) describes our econometric model and the data sets; Section [Results](#) reports and discusses the results; The final Section [Conclusion](#) draws conclusions.

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## Energy context in Tunisia

Energy resources in Tunisia mainly consist of oil and natural gas. Since 2001, Tunisia has passed from a positive balance status to a net energy importer status (Fig. 1 [12,13]).

Such a status can be explained by the stagnation of the national energy production against growing energy consumption. Greenhouse gases (GHG) emissions are caused by energy combustion resulting from six sectors: the energy processing industry (electricity production and refinement) and five end-energy consumption sectors which are the manufacturing industry, transport, housing, tertiary and agriculture sectors. In Tunisia, the typology of combustion-generated GHG emissions by type of gas shows that carbon

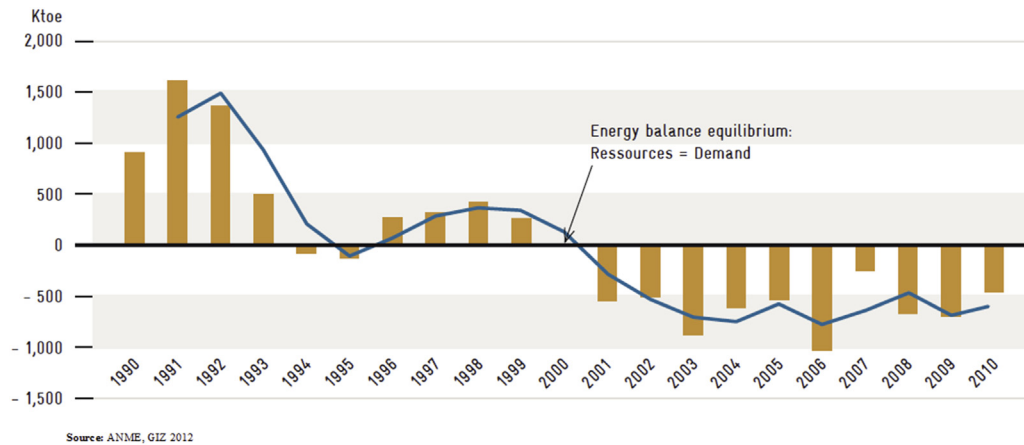


Fig. 1 – Evolution of energy balance in Tunisia.

dioxide emissions (CO<sub>2</sub>) dominate total emissions with almost 98.3%. The remainder is shared between methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) which respectively account for 1.1% and 0.6% of total combustion-generated emissions.

Recently, there has been a growing interest in energy mix transition as the domestic demand for energy is growing and hence the energy dependence structure has deep ended. In fact, Tunisia is implementing policies to support renewable energy in order to guaranty its energy supply and mitigate global climate change. Besides, and according to [13], a total of more than 8.3 billion DT will be spent on all renewable energy technologies until 2030 (See Fig. 2 [12,13]).

The aim is to make renewable energy contribute more to total end energy consumption by 2030 as illustrated in Fig. 3.

## Methodology

Annual data on GDP, CO<sub>2</sub>PC and RENE are collected from the World Bank [14]. These data will be analyzed by statistical tables and graphs. To study the linear relations between

these variables, we need the ARDL cointegration technique. It does not require pretests for the unit root unlike other models but it is preferred when the variables are integrated of order, I(0), I(1) or combination of the both. To determine the lags of the model we use the Akaike Information Criterion (AIC) and the Schwarz Bayesian Information Criterion (SIC).

## Data

Table 1 below presents the statistical properties of our variables. To test the distribution properties of these variables, we use Jarque-Bera, Skewness and Kurtosis as indicators. In a normal distribution kurtosis is 3, and skewness is 0. In what follows, more properties of these variables are presented.

CO<sub>2</sub> emissions (CO<sub>2</sub>PC): The chart below (Fig. 4) describes the evolution of CO<sub>2</sub> emissions per capita in Tunisia from 1990 to 2015.

We calculate the average annual growth rate of CO<sub>2</sub>PC during all the study period and over the past three decades. The results are shown in Table 2.

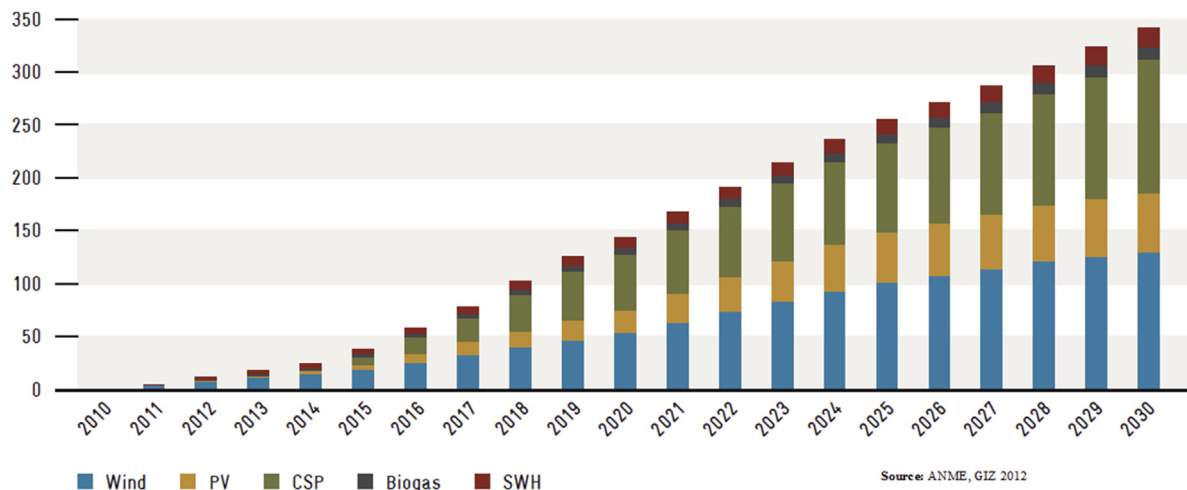


Fig. 2 – Investment on renewable energy, in TND2011 million.

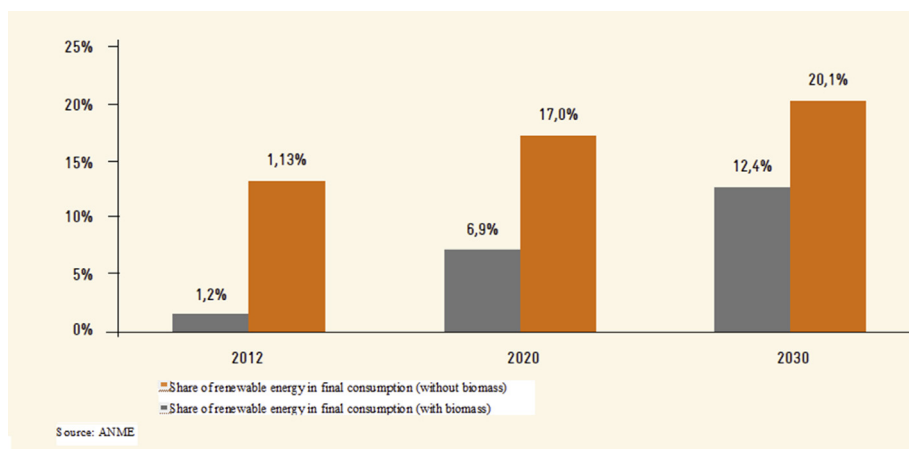


Fig. 3 – Renewable energy contribution to end-energy consumption in Tunisia.

Referring to Table 2, the two first decades (1990–2000) and (2000–2010) exhibit a higher average annual growth rate of CO<sub>2</sub> emissions per capita than that of all the study period 1,84% with respectively 2,28% and 2,1%. The most likely explanation is that these two decades reflect an economic growth cycle, marked by the creation of several industrial sites, an increased number of mines, cement production plants, and the importation tens of thousands of vehicles for domestic or administrative use in Tunisia. All these factors can be carbon dioxide emitters. Human capital seemed to be a

major environment polluter causing a large increase in CO<sub>2</sub> emissions.

Nevertheless, during 2000–2010, intensive measures have been implemented in Tunisia to reduce pollutant emissions and promote energy efficiency. As a result, the first half of the third decade exhibit a reduction in CO<sub>2</sub> emissions, which may resulted from shutting down production, in particular phosphate production following continuous strikes in that sector.

Table 1 – Statistical properties of variables.			
1990–2015	CO <sub>2</sub> PC	GDP	RENEC
Mean	2.155976	3.28e+10	14.08632
Median	2.158188	3.14e+10	14.24992
Maximum	2.622539	4.81e+10	16.07000
Minimum	1.627000	1.83e+10	12.13977
Std.Dev	0.302208	9.83e+09	0.797243
Skewness	-0.000168	0.104351	-0.566706
Kurtosis	1.737928	1.624237	4.357720
Jarque-Bera	1.725560	2.097636	3.388699
Probability	0.421987	0.350352	0.183719

Source: Authors calculation.

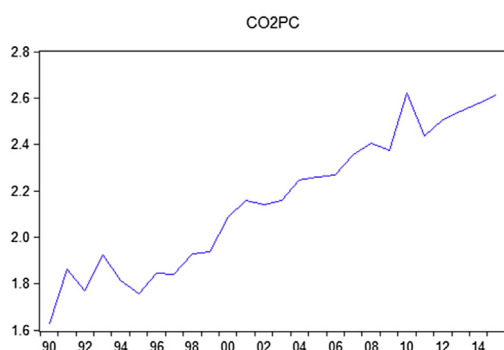


Fig. 4 – CO<sub>2</sub> emissions per capita in Tunisia, 1990–2015.

- Gross Domestic Product (GDP): in recent years, the relationship between economic growth and carbon emission has attracted much attention of some researchers like [15]. Generally, these studies indicated that it could be hard to separate economic growth from ecological issues and that global development bears a clear connection between economic development and increased greenhouse gas emissions that cannot be neglected. A strong correlation is then found between GDP and CO<sub>2</sub> emissions and can vary from one country to another depending on the economic development levels. Fig. 5 below shows that the two CO<sub>2</sub>PC and GDP series have almost the same trend in Tunisia. The vertical axis on the left represents GDP, whereas the vertical axis on the right indicates CO<sub>2</sub>PC emissions.
- Renewable energy consumption (RENEC): renewable energy use can have several positive effects on local and regional environment. We expect that renewable energy use induces a fall in CO<sub>2</sub> emissions in the long-run since it is a clean source of energy compared to non-renewable energy, the primary source of CO<sub>2</sub> emissions. The representation of Tunisian renewable energy consumption and CO<sub>2</sub> emissions evolution reveals the following trends (Fig. 6).

Table 2 – Average annual growth rate of CO<sub>2</sub> per capita in Tunisia.

q1990-2000	q2000-2010	q2010-2015	q1990-2015
2.28%	2.1%	-0.05%	1.84%

Source: Authors calculation.

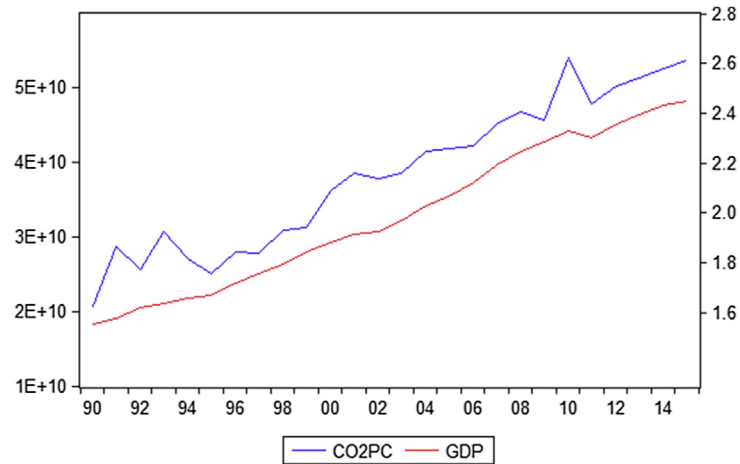


Fig. 5 – Joint graphic representation of GDP and CO2PC in Tunisia, 1990–2015.

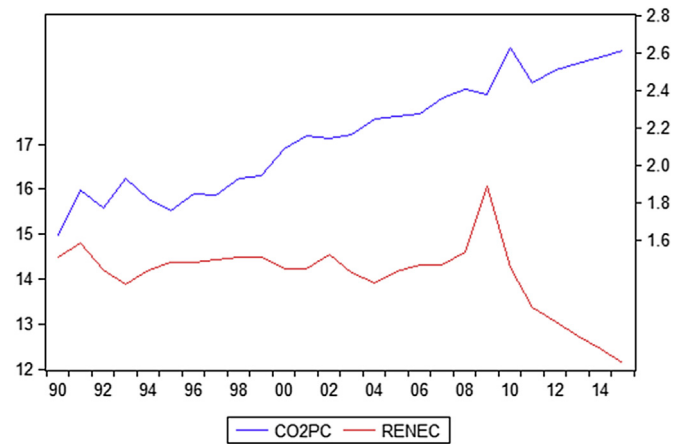


Fig. 6 – Joint graphic representation of Renec and CO2PC in Tunisia, 1990–2015.

The vertical axis on the left represents RENEC and that on the right represents CO2PC. Interestingly, the RENEC curve remains almost constant between 1990 and 2008 and exhibits an upturn in 2009, followed by a noticeable downturn during the rest of the period. Besides, by 2010, CO2PC reaches its maximum and maintains an increasing trend till 2015. This trend can be justified by the current difficulties facing the Tunisian economy after the revolution. The priorities of the Tunisian government have shifted to give more importance to regional development even at the expense of environment quality.

### Model presentation

We use the ARDL bound testing approach to examine the relationship between CO2 emissions, economic growth and renewable energy consumption. The ARDL approach introduced by Ref. [16] and developed by Ref. [17] has several advantages over the cointegration method presented by Refs. [18,19]:

- First, this approach does not impose the condition that the variables have the same order of integration. However, it takes into account variables that are order 1 or order 0 integrated.
- Next, it is adapted to small samples. In fact, Johansen's cointegration method requires a large number of observations for the estimation to be reliable.
- Finally, in the ARDL model, the dependent variable is explained by its past and by the past of the other independent variables.

The ARDL model includes order 1 lagged variables, and lagged differential variables whose order depends on the lag selection criterion. The long-run relationship between the variables is expressed by the coefficients  $\alpha$ ,  $\beta$ , and  $\gamma$  whereas the coefficients  $a$ ,  $b$  and  $c$  express the short-term relationship between the independent variables and the dependent variable. Then, we estimate the following ARDL models (1):

$$\begin{aligned}\Delta(\text{co2PC}) &= c + \sum_{i=1}^{m_1} a_{1i}\Delta(\text{co2PC})(t-i) + \sum_{i=1}^{p_1} b_{1i}\Delta(\text{gdp})(t-i) + \sum_{i=1}^{q_1} c_{1i}\Delta(\text{re nec})(t-i) + \alpha_1\text{co2PC}(t-1) + \beta_1\text{gdp}(t-1) + \gamma_1\text{re nec}(t-1) + \varepsilon_{1t} \\ \Delta(\text{gdp}) &= c + \sum_{i=1}^{m_2} a_{2i}\Delta(\text{co2PC})(t-i) + \sum_{i=1}^{p_2} b_{2i}\Delta(\text{gdp})(t-i) + \sum_{i=1}^{q_2} c_{2i}\Delta(\text{re nec})(t-i) + \alpha_2\text{co2PC}(t-1) + \beta_2\text{gdp}(t-1) + \gamma_2\text{re nec}(t-1) + \varepsilon_{2t} \\ \Delta(\text{re nec}) &= c + \sum_{i=1}^{m_3} a_{3i}\Delta(\text{co2PC})(t-i) + \sum_{i=1}^{p_3} b_{3i}\Delta(\text{gdp})(t-i) + \sum_{i=1}^{q_3} c_{3i}\Delta(\text{re nec})(t-i) + \alpha_3\text{co2PC}(t-1) + \beta_3\text{gdp}(t-1) + \gamma_3\text{re nec}(t-1) + \varepsilon_{3t}\end{aligned}$$

$\varepsilon_{1t}$ ,  $\varepsilon_{2t}$  and  $\varepsilon_{3t}$  are pure white noise error term.  $\Delta$  is the first difference operator.  $m_i$ ,  $p_i$ ,  $q_i$ ,  $i=1,2,3$  are the lagged values of  $\Delta$ .

Several criteria can be used to determine the number of lags. The most famous are Akaike Information Criteria (AIC) and Schwarz Bayesian Criteria (SIC) [20]. favor AIC, which has more theoretical advantages over SIC for three reasons: first because AIC is derived from information theory principles, unlike SIC. Second, because the hypotheses about the derivation of SIC are debatable. Finally, because some empirical studies suggest that AIC is more efficient than SIC. As indicated in Table 3 below, the direct application of AIC on the variables resulted in three lags.

Most of the time, economic and financial series are non-stationary. Then, the direct application of classical econometric techniques, even with correct assumptions, can lead to very aberrant results since the variables have no link between them. Before estimating the model, it is then necessary to check whether the series are stationary or not. The variables are then checked by the Dickey-Fuller (ADF) and Phillips-Perron (PP) tests [21].

The next section consists in applying the ordinary least squares method to estimate the ARDL model by order 3 equation. GDP, RENE and CO2 emissions per capita are treated as dependent variables. Then, we try to determine the existence of a long-run and a short-run relationship between variables. To test whether or not there is a correlation between series, we apply the serial correlation test LM. In the absence of long-run causality between CO2 emissions and economic growth, emphasis then should be placed on the use of clean sources of energy to reduce carbon emissions.

## Results

The study consists first in testing whether there is a causal relationship between the different variables. Then, we apply the augmented Dickey-Fuller and the Philips-Perron tests to

**Table 3 – Lagged selection criteria.**

Lag	Log L	AIC
0	-551.0795	48.18083
1	-475.3570	42.37887
2	-469.4060	42.64400
3	-456.4949	42.30390

Source: Authors calculation.

detect the presence or the absence of a unit root in our variables. Finally, we will use the ARDL model stage-wise to explore the relationship between CO2 emissions, economic growth and renewable energy consumption.

## Causality

We now examine the causal relationship between the three variables. “A variable X causes variable Y if the past values of X have a statistical impact on the current or future value of Y”. The results of Granger causality tests over the three variables are presented in Table 4 and illustrated in Fig. 7:

The null hypothesis that the GDP does not cause CO2PC is rejected with a probability  $p=3\%$  which is less than 5%. The GDP variable then exerts a causal effect on CO2PC emissions. GDP growth may come along an increase in CO2 emissions, but at a certain growth level, increase in GDP can have a negative effect on CO2 emissions. This is called the Kuznets effect and is illustrated by environmental Kuznets curve (EKC).

## Cointegration analysis

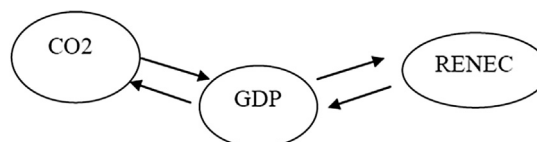
Three models are estimated sequentially to detect the presence or absence of a unit root. Initially, the model with a trend and a constant (M1) is estimated, if the trend is not significant,

**Table 4 – Lagged selection criteria.**

Null hypothesis	F-Statistic	Probability
GDP does not Granger Cause CO2PC	3.59686	0.0369
CO2PC does not Granger Cause GDP	5.79589	0.0070 (*)
RENEC does not Granger Cause CO2PC	1.49312	0.2543
CO2PC does not Granger Cause RENE	1.58240	0.2327
RENEC does not Granger Cause GDP	2.81708	0.0724 (***)
GDP does not Granger Cause RENE	4.30787	0.0208 (**)

(\*), (\*\*), (\*\*\*) : Null hypothesis is rejected respectively at 1%, 5% and 10%.

Source: Authors calculation.



**Fig. 7 – Causality graph.**

**Table 5 – Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests.**

Variables	ADF test				PP test			
	M1	M2	M3	RU	M1	M2	M3	RU
CO2PC	-4.440***	-0.043	3.165	0	-4.514***	-1.082	3.059	0
GDP	-2.210	0.263	7.858	1	-2.245	0.263	7.042	1
$\Delta(\text{GDP})$	-4.443***	-4.579***	-1.093	0	-4.443***	-4.579***	-1.484	0
RENEC	-1.598	-0.988	-0.878	1	-1.692	-1.065	-0.977	1
$\Delta(\text{RENEC})$	-4.976***	-4.948***	-4.871***	0	-5.159***	-4.973***	-4.877***	0
Critical values	-4,21***	-3,61***	-2,62***	0	-3,53**	-2,94**	-1,95**	

M1:model with a trend and a constant; M2:model with a constant; M3:model without a constant or a trend The RU column denotes the number of unit roots. If RU = 1 then the variable is non-stationary, if RU = 0 then the variable is stationary. The values in this table are t-statistics. (\*\*\*) and (\*\*) denote t-statistic which are significant the 1% and 5%levels, respectively.  
Source:Authors calculation.

the model with a constant (M2) is chosen. When the constant is not significant, the third model without a constant or a trend will be implemented (M3). For this purpose, two tests are used, the augmented Dickey-Fuller. Table 5 reports the obtained results.

We found that CO2PC is stationary in level, whereas GDP and RENE C are I(1). These findings suggest that the ARDL “Bounding test” approach is useful for our cointegration analysis and is appropriate to estimate the existence of long-run relationships between the variables.

#### ARDL estimation

The next step in our analysis consists in applying the ordinary least squares method to estimate the ARDL model where GDP, renewable energy consumption and CO2 emissions per capita are treated as dependent variables. Table 6 reports the results of the ARDL modeling. To allow for better results, we introduce the trend as an independent variable for the first two

models whose dependent variables are respectively CO2PC and GDP. However, for the third model whose endogenous variable is RENE C, we notice that introducing the trend would not improve the results.

To test the global significance of a model and to set forth a preliminary conclusion about the existence of long-run relationships between the variables, we need a Fisher test. In Table 6, the F-statistics of the two models whose endogenous variables are  $\Delta\text{CO2PC}$  and  $\Delta\text{GDP}$  are statically significant at the 1% level. Mean while, the model whose independent variable is  $\Delta\text{RENEC}$  exhibits an F-statistic significant at the 9% level.

Furthermore, the determination coefficients  $R^2$  and  $\bar{R}^2$  of the first and second model, show a better fit quality compared to those of the third model. Since  $R^2$  cannot arbitrate between the losses of degrees of freedom of the model and the resulting fit, we prefer to use Akaike or Schwarz criteria to retain the best model. In the three equations, the lagged variables with the operator  $\Delta$  denote the short-run relationship and the other variables denote the long-run cointegration relationships.

**Table 6 – ARDL estimates.**

Dependent variable	$\Delta(\text{CO2PC})$		$\Delta(\text{GDP})$		$\Delta(\text{RENEC})$	
	Coefficients	t-Statistic	Coefficients	t-Statistic	Coefficients	t-Statistic
C	-2.203	-1.75	-5.52E + 09	-0.71	26.502**	2.02
@TREND	0.060**	2.78	8.88E + 08***	6.31		
$\Delta(\text{CO2PC}(-1))$	-0.518	-1.41	-1.16E + 10***	-4.6	0.67723	0.17
$\Delta(\text{CO2PC}(-2))$	0.009	0.03	-1.02E + 10***	-5.72	-0.21531	-0.07
$\Delta(\text{CO2PC}(-3))$	0.491**	2.29			-1.42720	-0.64
$\Delta(\text{GDP}(-1))$	1.09E-10**	2.69	1.022034***	4.13	-1.84E-1	-0.04
$\Delta(\text{GDP}(-2))$	-3.51E-12	-0.15	0.982757***	6.01	6.4E-10***	2.79
$\Delta(\text{GDP}(-3))$	-	-	0.959831***	3.97	-	-
$\Delta(\text{RENEC}(-1))$	-0.140**	-2.27	-1.18E+09**	-2.72	0.95512	1.49
$\Delta(\text{RENEC}(-2))$	-0.141**	-2.81	-1.05E+09***	-3.07	0.62102	1.19
CO2PC(-1)	-0.564	-1.66	1.58E + 09	0.77	-1.8307**	-2.44
GDP (-1)	-2.98E-11	-1.48	-0.761817***	-5.55	-0.4384	-0.12
RENEC (-1)	0.241***	3.26	9.21E + 08**	1.99	-2.85E-12	-0.02
$R^2$	0.903940		0.940322		0.73430	
$\bar{R}^2$	0.771858		0.858264		0.43908	
AIC	-3.13596		41.89288		1.56999	
SIC	-2.53852		42.49032		2.11765	
DW	2.17673		2.216974		2.25830	
F-statistic	6.84378***		11.45924***		2.48734*	

(\*), (\*\*) and (\*\*\*) : the coefficients are significant respectively at level 10%, 5% and 1%.

Source:Authors calculation.

**Table 7 – LM test.**

CO2PC	F-statistic	1.207954	Prob. F (2,6)	0.3624
	Obs*R-squared	5.741289	Prob. Chi-Square (2)	0.0567
GDP	F-statistic	1.138055	Prob. F (2,6)	0.3810
	Obs*R-squared	5.500436	Prob. Chi-Square (2)	0.0639
RENEC	F-statistic	0.298697	Prob. F (2,7)	0.7508
	Obs*R-squared	1.572628	Prob. Chi-Square (2)	0.4555

Source: Authors calculation.

In the long-run, CO2 emission is explained by the trend and RENE. In the short-run, all three variables are statistically significant. GDP is explained in the long run by the trend, GDP (−1), and RENE (−1). In the long run, all lagged variables 1, 2 and 3 are statistically significant at the 5% level. Finally, RENE is negatively and significantly affected by CO2 emissions at the 5% level in the long-run. In the short-run, RENE is only affected by real GDP at the 1% significance level.

### Serial correlation test

Ignoring correlation between the variables may have serious consequences on the estimated parameters. The ordinary least square coefficients are still unbiased but inefficient. The variances of coefficients are biased and the tests are invalid. In our case, the F-statistic calculated for the three models imply the acceptance of the null hypothesis H0 (Table 7). As a consequence, the series are not correlated, then, the three models are retained.

### The CUSUM test

This step consists in applying the CUSUM test to predict the presence of a stable long-term relationship. The CUSUM test recursively calculates the regression coefficients and residuals at particular thresholds. Generally, detecting a threshold amounts to deriving a graph representing the different recursive statistics considered as a function of an ordered transition variable: a method commonly used in practice to identify thresholds. Fig. 8 exhibits the Cumulative Sum of Recursive residuals (CUSUM) graphs obtained from ARDL stability tests.<sup>1</sup> All the lines range between the critical bounds and no line crosses no critical bound throughout the span. These graphs provide evidence about the stability of the ARDL estimation results presented above.

### The bound-test

To test the long-run relationship between the underlying variables, we apply the Wald test. Statistically, the idea is to test under the null hypothesis:  $H_0: \alpha = \beta = \gamma = 0$  against  $H_1$  At least one of these coefficients is  $\neq 0$  We conclude to the long-run relationship of the series only when the F-statistic exceeds the critical band. Rejecting the null hypothesis means the presence of a long-run relationship, while its acceptance denotes the absence of a long run relationship. The results are summarized in Table 8 below.

<sup>1</sup> In CUSUM graph, residual values are in solid lines, while the dotted lines represent the confidence interval of the residues at a confidence level of 95%.

To check whether the variables are cointegrated or not, we should compare the F-statistic to I(0) and I(1) calculated and presented in Table 9, as a bound test [17]. If the computed F is higher than I(1), then we conclude to the existence of a long-run relationship. If F is less than I(0), then there is no cointegration. Finally, if the computed value is between I(0) and I(1), we can't conclude.

We conclude from Table 9, that there is a long-run relationship between CO2 emissions, growth and renewable energy consumption. In fact, for CO2PC, the F-statistic is 9.30 which we compare to the Pesaran critical value of 5%. According to the unrestricted intercept and trend Pesaran table, the lower-bound is 4.87 and the upper-bound is 5.85. The F-statistic is higher than the upper-bound (9.30 > 5.85). We draw the same conclusion for GDP. In fact, the F-statistic = 14.01 is higher than 5,85 and then we reject the null hypotheses. Besides, the F-statistic of RENE is 5. Compared to the upper bound of the model FIII 4.85 at the 5% level with an unrestricted intercept and no trend, the F-statistic is higher than 4.85. As a conclusion, there is a long relationship between RENE and the others variables. As a consequence, three error-correction models will be retained when investigating the long-run and short-run causal relationships.

### Introduction of the error correction model

We now apply the ordinary least squares method to the simple linear model:

$$CO2TET = C + \theta_{11}GDP + \theta_{12}RENEC + U_{1t}$$

$$GDP = C + \theta_{21}CO2TET + \theta_{22}RENEC + U_{2t}$$

$$RENEC = C + \theta_{31}GDP + \theta_{32}CO2TET + U_{3t}$$

We deduce from this equation the residual U, which will be retained as the error-correction term (ECT). We estimate model (1) by replacing the long-term relationship by the term lagged by one year ECT (−1). For the term to be interpretable, the sign of its coefficient must be negative and statistically significant. It expresses adjustment speed towards long-run equilibrium in case of shocks to the system. Table 10 reports the results in terms of the short-run coefficients:

$$\Delta(\text{co2PC}) = c + \sum_{i=1}^{m_1} a_{1i}\Delta(\text{co2PC})(t-i) + \sum_{i=1}^{p_1} b_{1i}\Delta(\text{gdp})(t-i) + \sum_{i=1}^{q_1} c_{1i}\Delta(\text{re nec})(t-i) + \gamma_1 ECT_1(-1) + \varepsilon_{4t}$$

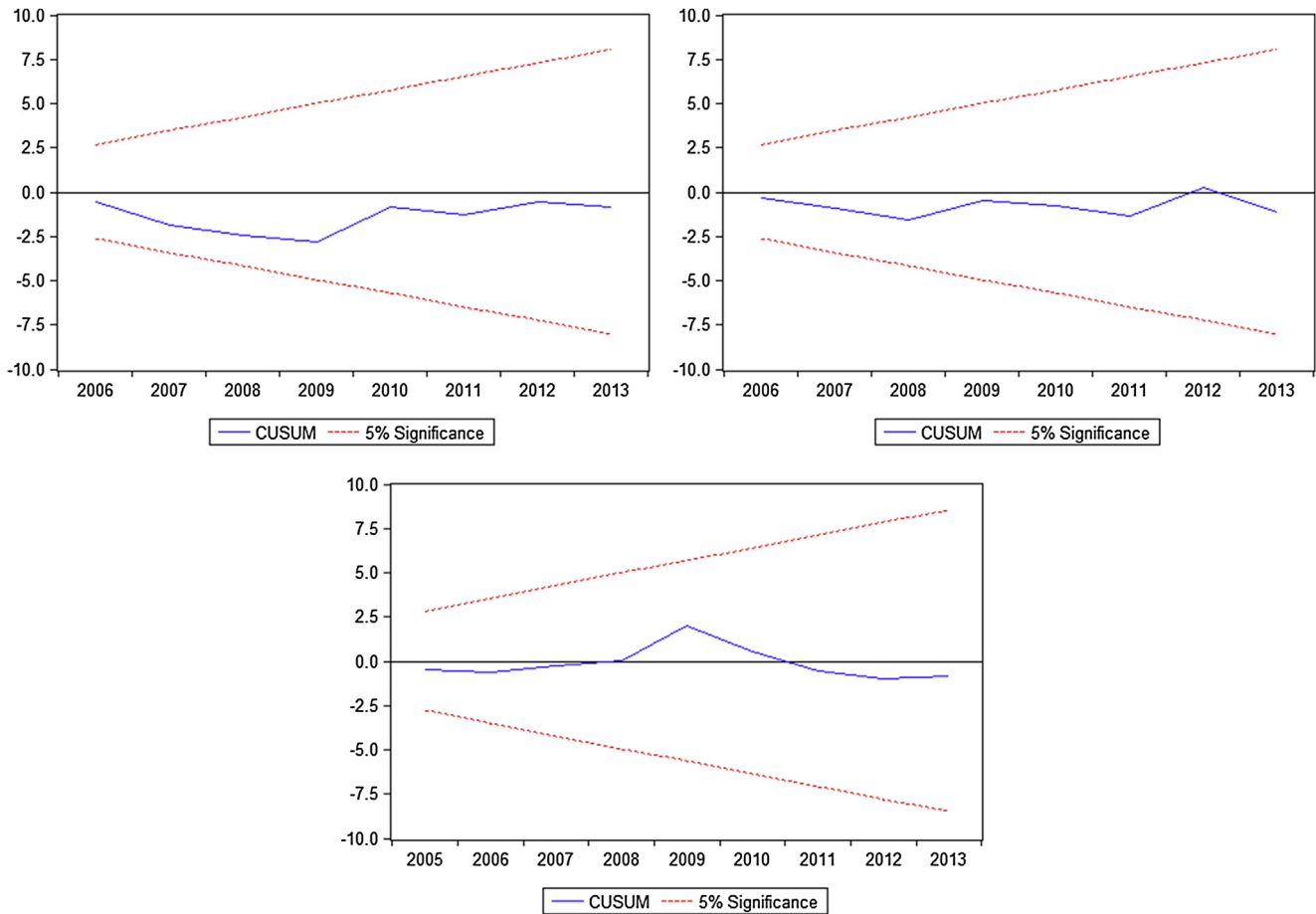


Fig. 8 – CUSUM test for CO2PC, GDP and RENE.

Table 8 – Wald-test results.

Variable	T-statistic	Value	Probability
CO2PC	F-statistic	9.305	0.005
	Chi-square	27.916	0.000
GDP	F-statistic	14.015	0.001
	Chi-square	42.047	0.000
RENEC	F-statistic	5.005	0.001
	Chi-square	15.016	0.000

Source:Authors calculation.

Table 9 – Critical values for the ARDL Model.

Probability	0.10		0.05		0.01	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
$F_{IV}$	3.38	4.02	3.88	4.61	4.99	5.85
$F_V$	4.19	5.06	4.87	5.85	6.34	7.52
$F_m$	3.17	4.14	3.79	4.85	5.15	6.36

Sources: [17].  $F_{IV}$  represents the F statistic of the model with an unrestricted intercept and a restricted trend,  $F_V$  represents the F statistic of the model with an unrestricted intercept and a trend, and  $F_m$  represents the F statistic of the model with an unrestricted intercept and no trend.

Source:Authors calculation.

$$\Delta(gdp) = c + \sum_{i=1}^{m_2} a_{2i}\Delta(co2PC)(t-i) + \sum_{i=1}^{p_2} b_{2i}\Delta(gdp)(t-i) + \sum_{i=1}^{q_2} c_{2i}\Delta(renec)(t-i) + \gamma_2 ECT_2(-1) + \varepsilon_{5t}$$

$$\Delta(renec) = c + \sum_{i=1}^{m_3} a_{3i}\Delta(co2PC)(t-i) + \sum_{i=1}^{p_3} b_{3i}\Delta(gdp)(t-i) + \sum_{i=1}^{q_3} c_{3i}\Delta(renec)(t-i) + \gamma_3 ECT_3(-1) + \varepsilon_{6t}$$

The error correction terms (ECM) in the three models are negative, with good signs. They are statistically significant, then, there is a return to a long-run equilibrium relationship. They also express adjustment speed towards equilibrium.

Moreover, the F-statistic is acceptable for GDP at the 1% level, while the F-statistic of RENE is 5% and the F-statistic of CO2PC is 10%. Hence, the equation of GDP is more significant in its entirety compared to the RENE and CO2PC equations. The high of the determination coefficients R for the three models show a better fit quality of the ARDL model. To check whether there is a joint effect of the lagged variables on the dependent variables, we apply the joint causality test. The results of the Wald test are shown in Table 11 below:

**Table 10 – Dynamic relationship between CO2 emissions, GDP and RENEK using The error-correction model.**

Dependent variable	$\Delta(\text{CO2PC})$		$\Delta(\text{GDP})$		$\Delta(\text{RENEK})$	
	Coefficients	t-Statistic	Coefficients	t-Statistic	Coefficients	t-Statistic
C	–0.031	–0.505	–1.09E+09**	–2.266	–0.832**	2.178
@TREND	0.0014	0.389	–32330805	–1.317		
$\Delta(\text{CO2PC}(-1))$	–0.063	–0.128	–1.27E+10***	–5.869	0.852	0.409
$\Delta(\text{CO2PC}(-2))$	0.360	0.810	–9.51E+09***	–5.184	0.666	0.290
$\Delta(\text{CO2PC}(-3))$	0.396	1.174			–0.310	–0.185
$\Delta(\text{GDP}(-1))$	2.35E-11	0.511	0.932***	4.537	1.32E-10	0.606
$\Delta(\text{GDP}(-2))$	–5.24E-12	–0.147	0.962***	4.613	6.08E-10***	2.845
$\Delta(\text{GDP}(-3))$			0.792**	2.700		
$\Delta(\text{RENEK}(-1))$	0.044	1.029	–6.58E+08**	–2.346	0.638**	2.162
$\Delta(\text{RENEK}(-2))$	0.013	0.394	–6.12E+08***	–3.264	0.412	1.345
ECT4 (-1)	–0.938*	–1.8914	–0.682***	–4.543	–1.527***	–4.004
R <sup>2</sup>	0.682363		0.878175		0.711554	
$\bar{R}^2$	0.396489		0.768533		0.501774	
AIC	–2.140027		42.40649		1.452158	
SIC	–1.642161		42.90436		1.900237	
DW	2.076622		1.994103		2.260665	
F-statistic	2.38694***		8.00947***		3.391916**	

(\*), (\*\*) and (\*\*\*) : the coefficients are significant respectively at level 10%, 5% and 1%.

Source: Authors calculation.

**Table 11 – Joint causality test.**

Independent variables	Dependent variable	F-statistic	Probability	Results
$\Delta(\text{GDP}(-1))\Delta(\text{GDP}(-2))$	CO2PC	0.160	0.8539	No joint causality
$\Delta(\text{RENEK}(-1))\Delta(\text{RENEK}(-2))$	CO2PC	0.626	0.5543	No joint causality
$\Delta(\text{CO2PC}(-1))\Delta(\text{CO2PC}(-2))$	GDP	17.65	0.0005	joint causality
$\Delta(\text{RENEK}(-1))\Delta(\text{RENEK}(-2))$	GDP	5.87	0.0205	joint causality
$\Delta(\text{CO2PC}(-1))\Delta(\text{CO2PC}(-2))\Delta(\text{CO2PC}(-3))$	RENEK	0.10	0.95	No joint causality
$\Delta(\text{RENEK}(-1))\Delta(\text{RENEK}(-2))$	RENEK	4.188	0.044	joint causality

Source: Authors calculation.

The F-statistic measures the joint significance of all short-run regressors. These regressors are statistically significant if their probability p is less than 5%. In Table 11, the differentials GDP and RENEK do not jointly cause CO2PC. However, the differentials of CO2PC and RENEK jointly affect GDP with a probability less than 5%. Moreover, the differentials of GDP jointly affect RENEK with a probability P = 4%, while the differentials of CO2PC do not affect RENEK.

## Conclusion

In this study, we tried to explain the long-run and short-run relationships between CO2 emissions, renewable energy consumption RENEK and gross domestic product GDP for Tunisia via an ARDL model. We examined cointegration and Granger-causality between these variables for the last three decades (1990–2015). The question was to what extent CO2-induced environmental degradation is influenced by GDP and RENEK. Granger causality is used to check the existence of short- and long-run causalities.

Empirically, we found a long-run equilibrium for all the variables. A CO2 emissions are explained by RENEK and trend in the long-run, while, in the short-run it is explained by the

past of the three variables of the study. RENEK is also influenced by CO2 emissions in the long-term. With the introduction of the error-correction-terms ECTs, we found a cointegration relationship between all variables. ECTs coefficients allow for measuring adjustment speed. Joint causality tests established short-run causality running from the past of one variable to the dependent variable.

In summary, economic growth generated an increase in fossil fuel consumption in Tunisia, which is the main reason for CO2 emissions. However, reduction of fuel consumption generated a problem to the economic growth process. Therefore, the solution is renewable energy. This explains the bidirectional relationship between renewable energy and economic growth. Renewable energy is important for economic growth as the latter improves the use of more renewable energy sources.

As for Tunisia's serious commitment to reducing CO2 emissions, there is still a long way to go. Renewable energy use as a solution seems to be slowed down by rising investment costs on new technologies. Such a trade-off explains the neutral relationship between CO2 emissions and RENEK.

In conclusion, setting clear targets on renewable energy consumption, is important to succeed energy transition in the

country and to make the conservation policy positively affects economic growth and reduces CO<sub>2</sub> emissions.

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