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ORIGINAL RESEARCH ARTICLE

The effects of economic growth, energy consumption and financial development on CO_2 emissions in Tunisia: ARDL bounds testing approach to cointegration

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ABSTRACT

This study aims to investigate the impacts of economic growth, energy consumption, and financial development on carbon emissions within the framework of the environmental Kuznets curve hypothesis for Tunisa from 1970 to 2018. The long-run relationship is examined by applying the autoregressive distributed lag (ARDL) bounds testing procedure to cointegration and error correction analysis. The empirical findings show a positive monotonic relationship between real GDP and carbon dioxide emissions (CO_2), which means that Tunisia has not yet reached the required level of per capita income to get an inverted U-shaped EKC. The results also reveal a positive impact on both the energy consumption and the financial development, suggesting that theses control variables lead to environmental damages by polluting the atmosphere in the long run. At the same time, the paper explores causal links between the variables by referring to the Toda and Yamamoto (1995) Causality Test, and it concludes that financial development and energy consumption play a vital role in the Tunisian economy to achieve sustainable environmental development. Therefore, policy makers should not only focus on economic development, but also undertake a solid green finance regulation to assume an active environmentally friendly processes, and the energy matrix should be transformed in favor of renewable energy to cope with environmental degradation and to ensure sustainable development in Tunisia.

Keywords: ARDL Bounds Testing; Environmental Kuznets Curve (EKC); CO_2 Emissions; Economic Growth; Financial Development; Energy Consumption

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1. Introduction

Over the past 50 years, the average global temperature on earth has increased by more than 0.18 °C each decade. The largest impact of climate change on the world economy have been critically assessed by several prominent scientists and researchers by using various modeling techniques and different proxy variables[1–3]. More recently, the Environmental Protection Agency (EPA)[4] proves that the causes of greenhouse gases (GHGs) from human activities are from building fossil fuels for energy production, transportation, industry, and agriculture. The International Energy (IEA)[5] evaluations indicate that the CO_2 gas which is exposed by the fossil fuel usage is constitutes more than 60% of the GHGs.

The interaction effect between economic growth and CO_2 emission is principally founded by the most environmental Kuznets curve, known as the EKC curve, which considers an inverted U-shaped curve, which examines a relationship between the level of economic development and environmental degradation. By referring to the EKC hypothesis, many authors have studied the link between GDP, energy consumption and CO_2 emissions. However, these empirical analyses and studies have demonstrated mixed results, which make an encouragement research framework for other study to explain this causal relationship by diverse significant academic researches.

In this alignment, the nexus between financial development and economic growth, as well as energy consumption and economic growth, has been the subject of intense research process especially in the last decades. However, the empirical research evidence remains, sometimes, debatable and unclear issues. While numerous authors examine the relationship among emissions, economic growth, energy use and financial development, few studies have analyzed the framework of Tunisia.

Detecting key factors influencing carbon dioxide emissions could help policymakers to implement specific policies in this regard. However, this set of objects should be done while attempting to maintain sustainable development that satisfies the requirements of the present without affecting the capacity of future generations, assuring the equilibrium between economic growth, care for the environment and social well-being. Our contribution, in this study, is to evaluate whether the structure of the financial development is a significant determinant of environmental sustainability that go with the progression of economic development. In the below paragraph, we will present briefly some information about the Tunisia economy/energy situation and financial development.

The Tunisia government made many significant decisions to limit the deterioration of the economic situation by adopting the structural adjustment plan in 1986, became a contracting party to the General Agreement on Tariffs and Trade (GATT) in 1990, the adherence to the World Trade Organization in 1994 and the ratification of a free trade agreement with the European Union in 1995.

After the Arab Spring (2011), the economy dropped but then improved with 2.81% GDP growth in 2014. Recently, Tunisia's economic growth is slowly gaining steam. After recuperating modestly to 2% in 2017, growth accelerated to 2.5% in 2018, supported by agriculture, tourism and export-oriented manufacturing industries[6].

Currently, Tunisia is facing a huge energy deficit which is caused by an increase in energy demand that exceeded the national production since 2000. Total energy consumption has continued rather constant since 2017. It augmented by 3.5%/year between 2000 and 2010 and more than 2.4%/year over 2011–2018. In the framework of the Solar Plan, the Tunisian government aims to reach 3,815 MW of installed solar capacity by 2030.

Tunisia was among the primary to introduce financial restructurings in the Middle East and North Africa (MENA) region. In spite of the restructurings realized in the Tunisian financial sector, the biggest challenges facing our economy remain, which must be undertaken in order for the sector to support and stimulate economic growth by providing financing to firms and firms and households. In 2018, total credit provided by financial part to the private sector represents 85.6% of GDP. The Tunisian financial sector could play a major role in financing the economy to successfully supporting the country if the necessary reforms are realized.

In its Clean Development Mechanism (CDM), Tunisia is committed to reducing its carbon intensity to below 2010 levels to a 13% in 2030 and a 41% reduction if international financing is accessible. Indeed, CO_2 emissions associated with fuel combustion increased regularly by 3%/year between 1990 and 2018 and have continued constant since then (26.4 $MtCO_2$ in 2019).

Due to the importance of global warming and climate change issue, our paper aims to examine the effects of real GDP, energy consumption, financial development on carbon emissions for Tunisia. Moreover, the specific goal is to suggest some recommendations that help the policymakers in different subject areas to reduce CO_2 emissions. Therefore, this objective will be done principally by answering the following interrogations:

- Is environmental Kuznets curve achieved in Tunisia?
- What does the relationship between carbon emissions and economic growth reveal?

- What is the impact of energy consumption/financial development on environmental degradation?
- What are lessons and the policy implications of the causality test?

To reach the preceding objectives, this paper uses econometric methods to investigate the long run equilibrium between the variables, the direction of a causal relationship among CO_2 emissions, economic growth, financial development and energy consumption in Tunisia. We applied the Autoregressive Distributed Lag (ARDL) modeling approach and the causality test of Toda and Yamamoto[7] to examine such associations. This paper uses the time series data method for a period between 1970 and 2018, downloaded from the World Development Indicators (WDI). The results might help to implement the sustainable energy finance available to energy transition projects in achieving the related sustainable development goals in Tunisia.

This paper is organized as follows: in the next section, we present a survey related to the environmental Kuznets curve (EKC). Section 3 contains a full description of technique used, empirical review about the Autoregressive Distributed Lag model, bounds test and causality analysis. The results are discussed in Section 4. Some conclusions and policy recommendations are drawn in the closing section.

2. Theoretical framework

This study aims at investigating the effect of real GDP, energy consumption, financial development Carbon dioxide emissions in Tunisia. Following the empirical study, rendering to Kuznets[8] is also known for the Kuznets curve, which suggests that income inequality was usually rising in the initial phase of economic development. In the later stages of the development process, inequality declines after a turning point, giving rise to the famous inverted U-shaped association between revenue and inequality.

The researchers related to the EKC curve postulate that a higher amount of income leads to a deterioration in the environment. According to this hypothesis, as an economy grows, environmental gravity increases in the early stages and then decrease. Fundamentally, higher levels of revenue may decrease pollution emissions (e.g., carbon dioxide, carbon monoxide, water vapor and particulate residue). Beckerman[9] indicates that over a lengthy period of time, the certain system to safeguard and improve your environment is to develop your economic growth to a certain level: to become rich. However, the initial phase of this curve has stimulated a considerable debate around the need for different representations of the association between economic activity and environment degradation.

Therefore, when economic development takes place in developing countries, the environmental quality will always improve once a certain level of output is reached[10]. The argument giving to which economic growth leads to a better environment is debated since it stimulates the hypothetical of leading to improve environmental performance. This policy seeks to decoupling the growth of GDP and the growth of environmental degradation[11]: with public plans ranging from command-and-control rules to manager trade, investment, subsidies, businesses and boost technologies that reduced dioxide emissions while permitting continued economic growth and development.

Since 1990, data of major kinds of pollutants has been available over the Global Environmental Monitoring System for Air (GEMS/Air), statistics database collection of the OECD, the CO_2 emissions assessments from Department of Energy's (DOE), etc. These indicators on accessibility of government data encourage several important research projects to exam the validity of the inverted-U shaped hypothesis for income and environmental degradation.

The initial empirical studies appear by Grossman and Krueger[12]; later, many literature surveys recapitulate the large empirical work done on the EKC. Our updated list contains those of Ekins[13], Stagl[14], Panayotou[15], Borghesi[16], Dasgupta *et al.*[17], Harbaugh[18], Hill and Magnani[19], Galeotti[20], and Yandle *et al.*[21].

Conclusively, as has been seen in the **Figure 1**, the association among per capita per capita income and CO_2 emissions appearances like an inverted-U curve. It indicates that economic development leads to better environment quality after the turning point income.

Recent EKC studies have tested in many shapes and directions, with alternative econometric models by inclusion of additional explanatory variables (energy, trade, financial development, tourism, urbanism, education, human development index, etc.).

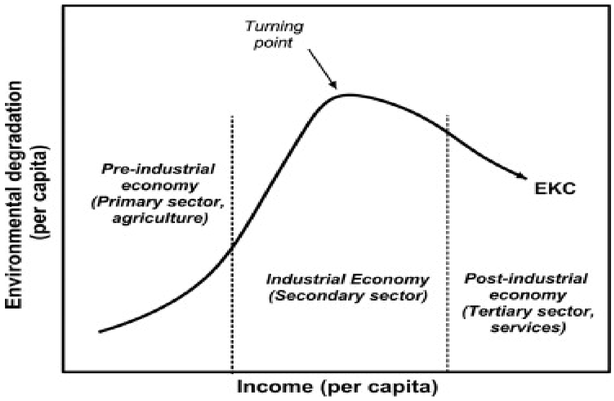

Figure 1. The plot of the environmental Kuznets curve (EKC)[8].

Based on this theoretical framework, we further evaluate whether the structure of the energy consumption and the financial organization matters for the degree of environmental degradation that go with the progression of economic development. In the following subsections, we will present the literature under three subcategories: economic growth/ energy consumption and CO_2 emissions, financial development and CO_2 emissions.

2.1 Economic growth and CO_2 emissions

The interaction between economic growth and CO_2 emission is principally founded by the environmental Kuznets curve (EKC) hypothesis, and the three interaction mechanisms between different pollutants and per capita income. These mechanisms are the scale effect of economic growth on pollution[22], the composition effect[23] and the technique effect[24].

The scale effect refers to an increase in CO_2 emissions due to a higher production level of goods and services from various resources, holding all other factors constant. Consequently, the sign of the scale effect is normally positive. The composition effect is explained by a variation in CO_2 emissions due to modification in the relative shares of different goods in the way of how to produce efficiently. If, for example, the exported good is relatively greenhouse-gas (GHGs) intensive, caused directly and indirectly, then the openness to trade may increase the economic activity implying a rise in environmental degradation.

The composition effect refers to the change in the basic source of its economic performance during the process of development of a country (production structure) from agricultural economies to industry and service-based which results in the reallocation of resources.

The technique effect indicates that the production of goods generates less GHGs due to the adoption of cleaner production techniques. This effect is caused mainly by sector energy intensity, change in input mix, etc. Trade can diminish pollution per unit of output by simplifying the transfer of cleaner technologies in order to improve the environmental performance will increase with income: use of smallest resources with maximum efficiency to achieve the resource conservation and environmental protection[25].

2.2 Emissions and financial development

In this study, the financial development, relative to the economy, defined as the total value of domestic credit to private sector as a share of gross domestic product. The importance of total value of domestic credit by banks to private sector arises from attract foreign direct investment (FDI) which in turn can stimulate economic development[26–29], and therefore affects the environmental performance index.

On the other hand, the reallocation of domestic credit to private sector can also have benefic effects by developing new means of reducing climate pollution and producing energy without having negative environmental impacts like wind turbines, hydroelectricity, solar energy, wastewater treatment, etc. In this sustainability orientation, the policy makers must accord more attention to the environmental issues related to goods and services industry which improve competitiveness, social welfare and stability[30–33].

Finally, differing to the previous reasons, the total value of domestic credit by banks to private sector may accelerate economic growth, it may result in more manufacturing or industrial process that are an important factor to contaminate and causing an environmental degradation[26,34,35].

2.3 Emissions, GDP and energy

Energy use is the most important determining factor in the study of the as environmental Kuznets curve hypothesis, which contains both renewable and fossil fuel energy sources. The environmental degradation is closely related to energy since more energy consumption leads to higher economic growth through the boosting of productivity but it also causes significant environmental impact. Many authors have founded that energy consumption has a significant positive impact on CO_2 emissions[36–40].

Many empirical studies have discussed the dynamic causal interrelationship between energy consumption, CO_2 emissions and output[41–44]. They prove that these variables are strongly inter-related to each other, and therefore their relationship must be examined using diverse statistical modeling techniques. The empirical results provide evidence for the existence of a strong long-run relationship between these variables. The causality results support the argument that economic growth exerts a causal influence both on the energy use and the pollution in the long run.

Since the last decade, many authors have reviewed the validity of the Kuznets curve and explored the existence of an inverted U-shaped relation between revenue per capita and environmental degradation. **Table 1** summarizes recent EKC studies.

Table 1. The collected reviews of literature related to the EKC

Author(s)	Country	Period	Methodology	Results
Jalil and Mahmud[45]	China	1975–2005	ARDL methodology	Inverted U-shape association between economic growth and CO_2 emissions
Pao and Tsai[10]	Panel of countries	1980–2007	Panel cointegration framework	Confirmed the EKC hypothesis only for China
Esteve and Tamarit[46]	Spain	1957–2007	Linear cointegration model	The results did not support the EKC hypothesis
Saboori *et al.*[47]	Malaysia	1980–2009	ARDL bounds approach, VECM Granger causality	The result supports the EKC hypothesis of an inverted-U curve
Ren *et al.*[48]	China	2000–2010	Generalized methods of moments technique	Inverted U-shape relationship between GDP and CO_2
Rafindadi[49]	Japan	1971–2012	ARDL approach	Inverted U-shape association between CO_2 and GDP
Apergis *et al.*[50]	United States	1960–2010	Common correlated effects approach	Inverted U-shape association between CO_2 and revenue
Awad and Warsame[51]	54 African countries	1990–2014	Semiparametric panel fixed effect regression	The result did not provide evidence in favor of EKC hypothesis
Shahbaz *et al.*[52]	China	1970–2012	ARDL	Inverted U-shape relationship between CO_2 and GDP
Riti *et al.*[53]	China	1970–2015	Multiple cointegration techniques	Confirmed the EKC relationship
Shahbaz *et al.*[54]	France	1955–2016	Bootstrapping ARDL	Inverted U-shape association between CO_2 and GDP
Beşe and Kalayci[55]	Egypt, Kenya and Turkey	1971–2014	Johansen cointegration model	No evidence for the EKC hypothesis in these countries
Alam and Adil[56]	India	1971–2016	ARDL approach	Insignificant relationship between CO_2 and GDP
Bah *et al.*[57]	10 middle-income countries	1971–2012	Panel cointegration approach	The EKC hypothesis is provided only in Nigeria, Cote d'Ivoire, Kenya, Mauritius, South Africa, and Botswana

Source: Authors.

3. Data, methodology and model specification

3.1 Data

In this paper, we use CO_2 (carbon emission metric tons per capita) as dependent variable, Gross Domestic Product (the economic growth per capita), EC (the energy consumption per capita) and FD (the financial development that is the total value of domestic credit to private sector as a share of GDP) as independent variables. These data are downloaded from World Development Indicators of World Bank in period spanning 1971–2018.

3.2 Methodology

In order to examine the long-run relationship between real GDP, energy consumption, financial development and carbon emissions in Tunisa during the period 1970 to 2018, an autoregressive distributed lag (ARDL) modeling approach has been applied in this study by using EViews 12 software. Furthermore, the bounds test is implemented for cointegration technique to estimate the long run relationship between variables of interest.

Contrary to the Vector Autoregression (VAR) model that is strictly used for endogenous variables, ARDL is a general specification taking into account the lag structure and it uses both endogenous and exogenous variables. These methods developed by Pesaran *et al.*[58] and Pesaran and Shin[59] have many advantages in the EKC analysis within Tunisia.

First, the ARDL method for small and finite sample sizes is more appropriate than the Johansen approach.

Second, this approach tests the cointegration relationship without requiring the same order of integration of all series[60].

Finally, compared to other econometric methods that require multiple equations to be estimated, the ARDL model simultaneously generates long-run and short-run relationships between the dependent and independent series by an error correction model (ECM) in only one equation setting, which makes it simpler to estimate and interpret various effects.

The question of environmental pollutants is a point which needs to be considered in developing countries as they need more energy consumption for higher real incomes. Following the empirical literature[2,41,43,61–64], the empirical relationship between variables of our model, can be expressed as the mathematical model presented in the next subsection.

3.3 Model specification

$$ln(CO_2)_t = \alpha_0 + \alpha_1\, ln(GDP)_t + \alpha_2[ln(GDP)]_t^2 + \alpha_3\, ln(EC)_t + \alpha_4\, ln\, FD_t + \varepsilon_t \quad (1)$$

where the subscript $t = 1 \ldots, t$ represents the time period.

CO_2 is carbon emission per capita, GDP measures the economic growth per capita (constant 2010 US$ per capita), GDP^2 is the square of GDP, EC is the energy consumption per capita, FD is the financial development and ε_t is the error term.

The parameters α_1, α_2, α_3, and α_4 are the long-term elasticity of CO_2 emissions with respect to per capita GDP, the squared per capita GDP, energy consumption and financial development correspondingly. Depending on the sign of the different α_i (where $i = 1, 2, 3, 4$) parameters related to long-term elasticity, the EKC will implement different shapes:

- If $\alpha_1 = \alpha_2 = 0$, there will be either a flat pattern or no relationship between environmental degradation and revenue.
- If $\alpha_1 > 0$ and $\alpha_2 = 0$, we will see a monotonic increasing relationship such that environmental deterioration increases along with income.
- If $\alpha_1 < 0$ and $\alpha_2 = 0$, we will see a monotonic decreasing relationship between environmental deterioration and revenue.
- If $\alpha_1 > 0$ and $\alpha_2 < 0$ and $\alpha_3 = 0$, there will be a classical inverted U-shaped EKC.
- If $\alpha_1 < 0$ and $\alpha_2 > 0$, there will be a U-shaped relationship between environmental deterioration and revenue.

The coefficient of energy consumption α_4 is expected to be positive, because a higher level of energy use should stimulate CO_2 emissions. Several studies examined these relationships[44,63,65–69]. Indeed, Energy consumption has a decisive impact on CO_2 dioxide emissions. So, energy consumption is a crucial factor in environment degradation. According to International Energy Agency[5] and the world bank report[70], the energy consumption of fossil is the main source of CO_2 emissions: energy consumption and carbon emissions are interrelated.

The expected sign of the financial development, α_4, may be either positive or negative.

- If we consider that financial sector development may be damaging for environmental quality then $\alpha_4 > 0$, not only directly but also indirectly. Indeed, many studies demonstrate that the financial development increases demand for energy and consequently is not favorable to improving environmental quality[42,71,72].
- If the goal of the financial sector is to prompt technological innovation and thus improve environmental quality by permitting firms in adopting advanced green technologies and environment friendly systems having significant effects on the environment or on human health then $\alpha_4 < 0$[25,63,73–76]. Thus, authors assert that financial development should prompt the green technology innovation improving the environmental quality and contributing to the achievement of sustainable development goals.

Table 2. Descriptive statistics (1970–2018)

	LCO_2	LEC	LFD	LGDP	$LGDP^2$
Mean	0.547724	6.449190	1.482715	7.861743	61.93092
Median	0.588712	6.455297	1.493148	7.789509	60.67645
Maximum	1.022506	6.898387	1.555882	8.391259	70.41323
Minimum	−0.301963	5.730059	1.345330	7.133607	50.88835
Std. Dev.	0.346774	0.337411	0.049028	0.355678	5.593088

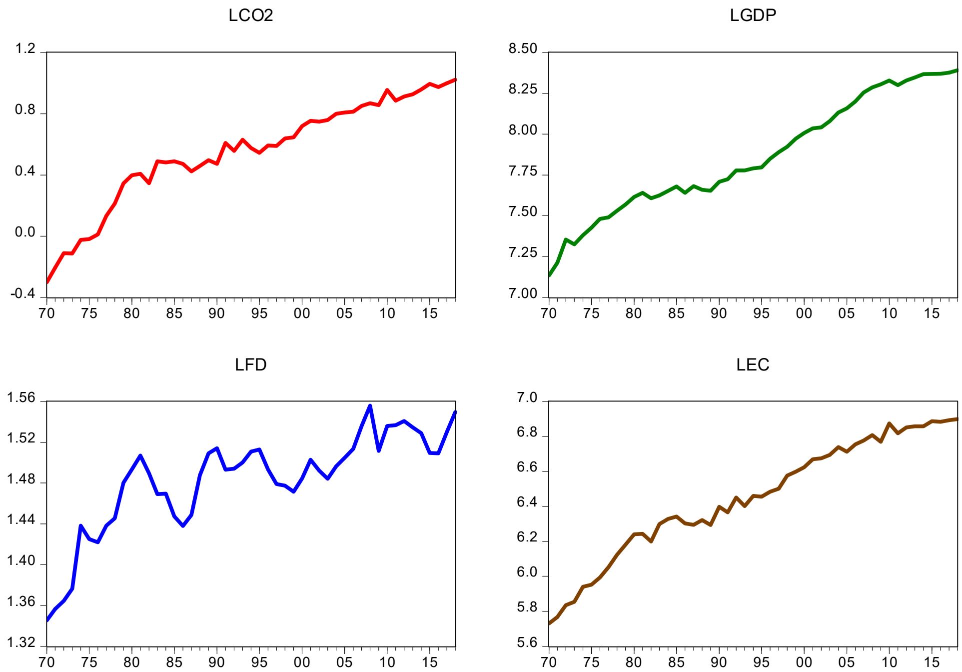

Figure 2. Pot of $\ln(CO_2)$, ln(GDP), ln(EC), and ln(FD).

3.4 Estimation strategy

This study chose the cointegration method of the ARDL model in a recursive format to test for cointegration associations the long run relationship between series with different order of integration between series and formulate the conditional error correction model as:

$$\Delta ln(CO_2)_t = \beta_0 + \sum_{i=0}^{p} \beta_{1i}\, \Delta ln(CO_2)_{t-i} + \sum_{i=0}^{q} \beta_{2i}\, \Delta ln(GDP)_{t-i} + \sum_{i=0}^{q} \beta_{3i} \Delta(ln (GDP))_{t-i}^2 + \sum_{i=0}^{q} \beta_{4i}\, \Delta ln(EC)_{t-i} + \sum_{i=0}^{q} \beta_{5i}\, \Delta ln(FD)_{t-i} + \beta_6\, ln(CO_2)_{t-1} + \beta_7\, ln(GDP)_{t-1} + \beta_8 (ln (GDP))_{t-1}^2 + \beta_9\, ln(EC)_{t-1} + \beta_{10} ln(FD)_{t-1} + w_t \quad (2)$$

In the above equation, the operator Δ indicates the first difference. ω_t represents the white noise error, β_0 is intercept while the parameters like β_{1i}, β_{2i}, β_{3i}, β_{4i}, and β_{5i} express the short run dynamics of the estimated model. β_6, β_7, β_8, β_9, and β_{10} represent the long run elasticities in the ARDL model.

Equation (2) is estimated using the ordinary least squares (OLS) regressions to test for cointegration relationships among CO_2 emissions, economic growth, energy consumption, and financial development by conducting a Wald test/F-test to ascertain the joint significance of the lagged coefficients of the variables.

Therefore, to test relationships among environment degradation, economic growth, energy consumption and financial development, we must estimate Equation (2) by the OLS technique. This procedure will be completed by performing a Wald test/F-test for the joint significance of the coefficients of lagged levels of the variables. To achieve this task, the null and alternative hypothesis are given as under:

$$\begin{cases} H_0 : \beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = 0 \\ H_A : \beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10} \neq 0 \end{cases}$$

Pesaran *et al.*[58] provided critical values for testing the null or alternative hypothesis of no cointegration. Indeed, under a certain significant level, if the output F-statistics is larger compared to the upper bound critical value, the null hypothesis is rejected, and so it is concluded that there is a long run relationship among the variables. If the value of F-statistics is inferior to the upper level of the band, then we cannot reject the null hypothesis and so there is no cointegration between the variables.

In 2005, Narayan proves that existing critical values which are founded on large sample sizes cannot be applied for small sample sizes. Consequently, the author regenerates the set of critical values for the limited data ranging from 30 and 80 observations. Subsequently, our study employs limited annual time series data (48 observations), then the critical values of Narayan[77] can be used for the bounds Fisher test instead of that of Pesaran *et al.*[58]. The error correction model (ECM) of Equation (2) is presented as follows:

$$\Delta ln(CO_2)_t = \varphi_0 + \sum_{i=1}^{p} \varphi_{1i}\, \Delta ln(CO_2)_{t-i} + \sum_{i=1}^{q} \varphi_{2i}\, \Delta ln(GDP)_{t-i} + \sum_{i=1}^{q} \beta\varphi_{3i} \Delta(ln(GDP))_{t-i}^2 + \sum_{i=1}^{q} \beta\varphi_{4i}\, \Delta ln(EC)_{t-i} + \sum_{i=1}^{q} \varphi_{5i}\, \Delta ln(FD)_{t-i} + \mu ECT_{t-1} + \vartheta_t \quad (3)$$

Therefore, when we substitute the long-run term

$$[\beta_6\, ln(CO_2)_{t-1} + \beta_7\, ln(GDP)_{t-1} + \beta_8 (ln(GDP)_{t-1}^2 + \beta_9\, ln(EC)_{t-1} + \beta_{10}\, ln(FD)_{t-1}]$$

with its residuals (ECT_{t-1}), the ARDL model reverts to error correction model. So, in Equation (3), μ represents the coefficient of the error correction term. This parameter shows the speed of adjustment of the variables toward long-run convergence.

4. Empirical results

4.1 Unit root tests

Before making the bounds test for cointegration and Granger causality tests, a unit root test for the concerned variables is necessary to ensure that variables are integrated of different order: mixture of integration of order I(1) and I(0). To ascertain the order of integration of the underlying series, our study begins through applying the Augmented Dickey Fuller and Phillips Perron unit root tests.

The results of the unit root tests show that the null hypothesis is rejected for the variables LEC and LFD referring to the ADF tests. Consequently, these variables are stationary in the level, I(0). For the variables LCO_2, LGDP and $LGDP^2$, both the

ADF and PP test statistic fail to accept the null hypothesis for unit root. However, through differencing this time series (where needed), both tests indicate that null hypothesis of unit root is rejected and that they are integrated of order one I(1).

Table 3. Unit root test

Variables	ADF test at levels	ADF test at first difference	Phillips-Perron test at levels	Phillips-Perron test at first difference
LCO_2	−2.95**	–	−3.18*	−9.02***
LGDP	−2.07	−6.88***	−2.86	−7.06***
$LGDP^2$	−1.77	−6.89***	−2.52	−6.99***
LEC	−3.27**	–	−2.54 (0.306)	−11.50***
LFD	−3.59**	_	−2.83*	−6.29***

*, ** and *** indicate stationarity at 10%, 5% and 1%, respectively.

4.2 The bounds test

As argued in the previous subsection, the ARDL bounds testing approach can be referred regardless of whether the variables are in mixed orders of integration (I(0) or I(1)). The F-statistics reported from the bounds test are extremely sensitive to the selected lag lengths when testing the cointegration to identify the long-term relationships between variables. In this paper, the Schwarz information criterion (SIC) is implemented to reach the optimal lag length for each variable, since in the small sample time series, this criterion lag specification is better than the others. For our model, the SC information criterion recommends that the bounds test results and the optimum lag length is equal to (1, 0, 0, 1, 2). The following table indicates that, the F-statistics (8.136) exceeds the higher limit values at 1% level of significance. This indicates the rejection of the null hypothesis that no cointegration exists between sets of variables and tends to be in favor of the alternative hypothesis. Hence, this test result suggests that there exists a cointegration between LCO_2, LGDP, $LGDP^2$, LEC, and LFD.

Table 4. ARDL bounds test results

	Value	Signif.	I(0)	I(1)
F-statistic k	8.136*** 4	10%	2.62	3.75
		5%	3.16	4.30
		1%	4.34	5.86
t-statistic	−5.981***	10%	−2.57	−3.66
		5%	−2.86	−3.99
		1%	−3.43	−4.6

Notes: k represents the number of independent variables. *, ** and *** indicate 10%, 5% and 1% of significant levels, respectively. Critical values are obtained from Narayan[77] for case 3 with 47 observations.

Having rejected the null hypothesis states that there is no long-run relationship exists between the variables, the ARDL (1,0,0,1,2) estimates for this model is presented in **Table 5**.

4.3 Estimation of ARDL level equation and error correction model

Given the presence of a long-run relationship among the variables of interest, the ARDL bounds procedure to examine the cointegration relationship was implemented to estimate Equation (2). The long-run and short-run results are reported in the following table, where all estimated coefficients are statistically significant at 5% level.

As presented in the theoretical framework, under the domain of the EKC hypothesis, the long-term elasticity of carbon dioxide emissions with respect to per capita GDP, the squared per capita GDP expected to be $\alpha_1 > 0$ and $\alpha_2 < 0$, respectively.

However, the long run coefficients estimated by the ARDL model show that as per capita GDP increases, per capita carbon emissions decrease as well, until some threshold level of per capita output is achieved, then CO_2 emissions commence to increase. There will be a U-shaped relationship between environmental degradation and revenue.

The results showed by the ARDL estimations indicate that a 1% rise in GDP will lead to about 4.83% decline in per capita CO_2 emissions. The

Table 5. Optimal ARDL model

Dependent variable: LCO_2
Method: ARDL
Dynamic regressors (4 lags, automatic): LGDP, $LGDP^2$, LEC, and LFD
Number of models evaluated: 625
Selected model: ARDL (1, 0, 0, 1, 2)

Variable	Coefficient	Std. error	*t*-statistic
$LCO_2(-1)$	0.045	0.15	0.28
LGDP	−4.61	2.50	−1.84
$LGDP^2$	0.25	0.14	1.75
LEC	0.84	0.26	3.21
LEC(−1)	0.59	0.23	2.57
LFD	0.72	0.36	1.97
LFD(−1)	−0.47	0.49	−0.96
LFD(−2)	0.80	0.36	2.22
C	10.27	8.88	1.15

R-squared: 0.98
Adjusted *R*-squared: 0.98
Durbin-Watson stat: 2.00
Log likelihood: 94.69
F-statistic: 425.01

Table 6. Estimation of error correction model (ECM) and ARDL level equation

Long run coefficients			
Variable	**Coefficient**	**Std. error**	***t*-statistic**
LGDP	−4.83	2.41	−2**
$LGDP^2$	0.26	0.14	1.88*
LEC	1.51	0.23	6.39***
LFD	1.11	0.31	3.63***
Short-run coefficients			
C	10.27	1.53	6.71***
D(LEC)	0.84	0.15	5.62***
D(LFD)	0.73	0.30	2.42***
D(LFD(−1))	−0.81	0.31	−2.65**
CointEq(−1)*	−0.95	0.14	−6.71***

R-squared: 0.61
Adjusted *R*-squared: 0.57
S.E. of regression: 0.034
Durbin-Watson stat: 2.01
Log likelihood: 94.69

$$\mathbf{EC = LCO_2 - (-4.83 \times LGDP + 0.26 \times LGDP^2 + 1.51 \times LEC + 1.11 \times LFD)}$$

The symbols *, **, and *** indicate 10%, 5%, and 1% of significant levels, respectively.

long-run estimates of per capita carbon emissions with respect to the square of GDP per capita is about 0.26%. This indicates that the empirical results and their implications for long-term relationship does not support the EKC hypothesis in Tunisia. This means that CO_2 emissions declines at early level of economic growth then reaches a turning point and increases with the developed level of economic growth. Similar to this finding, other studies have also not supported the EKC hypothesis of Esteve and Tamarit[46], and Awad and Warsame[51].

The long-run estimates of per capita carbon emissions with respect to financial development has a long-run positive influence. Indeed, a 1% rise in financial development will increase CO_2 emissions by 1.11%. This indicates that the domestic credit to private sector deteriorate environmental quality by causing air pollution, thus having a negative effect on human health. Our results take the same direction as that of Charfeddine and Montassar[78], Shahbaz *et al.*[68], Jiang and Ma[70], and Zhang[72].

In context from reliable sources, such as that of Wang *et al.*[79], in the long run, the estimated elasticity for energy consumption shows a negative effect on environmental quality in Tunisia. It indicates that an increase in per capita energy consumption by 1% will result in an increase in CO_2 emissions by 1.51%.

The error correction model was also estimated within the ARDL approach. The first part the ECM contains the estimated coefficients of short run dynamics. The second part contains the estimates of the error correction term that measures the speed of adjustment, calculated from the long-term relationship, allowing short-run dynamics converge to the long-run equilibrium. The results for the 1970 to 2018 period show that this term is negative, significant at the 5% and is equal to −0.95, which signifies that CO_2 emissions touch the equilibrium by 95% speed of tuning in the long-term, affected by real GDP, energy consumption, and financial development.

4.4 Toda and Yamamoto causality test

In order to explore Granger causality (1961) test, Toda and Yamanoto[7] established an approach based on the estimation of augmented Vector Autoregressive model (VAR). This test is based on Wald's "W" statistic and is distributed according to a Chi-squared statistic. The null hypothesis states the absence of causality between variables (probability >5%). The following table summarizes the results according to Equation (1).

The bidirectional nexus between economic growth and energy consumption (feedback hypothesis) is due to the energy used in Tunisia is very sensitive to fluctuations in economic growth. Indeed, when the economy of Tunisia shows a rapid growth, the energy consumption growth in an exponential way[38]. Correspondingly, the total factor productivity caused by real GDP influence the energy consumption[80].

Table 7. Results of Toda and Yamamoto causality test

	Explanatory variables				
Dependent variables	**LCO_2**	**LGDP**	**$LGDP^2$**	**LEC**	**LFD**
LCO_2	–	1.60 (0.44)	1.54 (0.46)	0.44 (0.8)	0.86 (0.64)
LGDP	10.05*** (0.00)	–	6.26** (0.04)	11.81*** (0.00)	3.87 (0.14)
LGP^2	9.73*** (0.00)	6.28** (0.04)	–	11.32*** (0.00)	3.81 (0.14)
LEC	7.13** (0.02)	6.37** (0.04)	6.39** (0.04)	–	1.51 (0.46)
LFD	13.89*** (0.00)	16.54*** (0.00)	15.5*** (0.00)	16.47*** (0.00)	-

The symbols *, **, and *** indicate 10%, 5%, and 1% of significant levels, respectively.

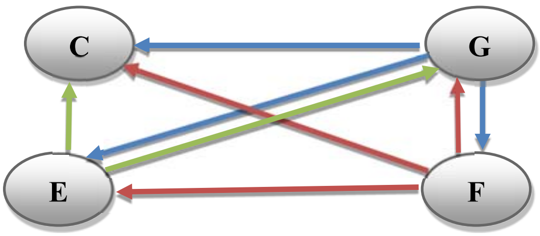

Figure 3. Causality graph.

Source: Authors.

The previous graphic summarizes the Toda and Yamamoto causality results. According to this test, in the long run, GDP, squared GDP energy consumption and financial development Granger cause CO_2 emissions. This provides the existence of a unidirectional long-run causality from the explanatory variables of our regression model to per capita carbon emissions.

The causal graph represents also two subsystems with bidirectional causality. The first feedback hypothesis shows a bidirectional causality between energy consumption and real GDP is due to the energy consumption in Tunisia is very sensitive to fluctuations in economic growth[38,81].

The second indicates a reciprocal relationship between real GDP and financial development. This result means that the policy interventions towards either financial development or economic growth could be advantageous to Tunisian economy. This result confirms the studies that have supported the feedback between economic growth and financial development[82–85].

4.5 Coefficients diagnostics

The results of the Breusch-Godfrey Serial Correlation LM test reveal that there are no serial correlations in the model residues. The result of Ramsey RESET test shows that in the model there are no omitted variables. The heteroskedasticity test (white) of the residuals of the specified equation proves that the variance for all observations is the same. Finally, the Jarque-Bera test is used to compare the shape of a given distribution referring to skewness and kurtosis. The normality test accomplishes that the model residues have a normal distribution.

Table 8. Coefficients diagnostics

Breusch-Godfrey serial correlation LM test			
F-statistic	0.438647	Prob. F (2.36)	0.6483
Obs**R*-squared	1.118109	Prob. Chi-square (2)	0.5717
Heteroskedasticity test: White			
F-statistic	1.596863	Prob. F (8.38)	0.1583
Obs**R*-squared	11.82514	Prob. Chi-square (8)	0.1592
Scaled explained SS	6.307745	Prob. Chi-square (8)	0.6128
Ramsey RESET test			
Specification: LCO_2 $LCO_2(-1)$ LGDP $LGDP^2$ LEC LEC(−1) LFD LFD(−1) LFD(−2) C			
	Value	**df**	**Probability**
t-statistic	1.302344	37	0.2008
F-statistic	1.696100	(1.37)	0.2008
Normality test			
Jarque-Bera	0.404	Prob.	0.816

4.6 Stability tests

To examine the stability of the long-run parameters together with the short-run movements for the equations (stability of the model), we use the cumulative sum (CUSUM) and cumulative sum squares (CUSUMSQ) tests of Borensztein *et al.*[86].

The following figures plot the CUSUM and CUSUM of squares statistics. It can be seen that the plot of CUSUM which is based on the cumulative sum of the recursive residuals, and is in the interior of the critical 5% bounds that confirms the long-run relationships among variables of the model and thus illustrates the stability of coefficient. Though CUSUMSQ statistics is slightly greater than the 5% critical bounds of parameter stability, it indicates instability of the coefficient at strict significant level. Consequently, these tests indicate the absence of any instability of the coefficients and suggest that the measured parameters are steady over the periods.

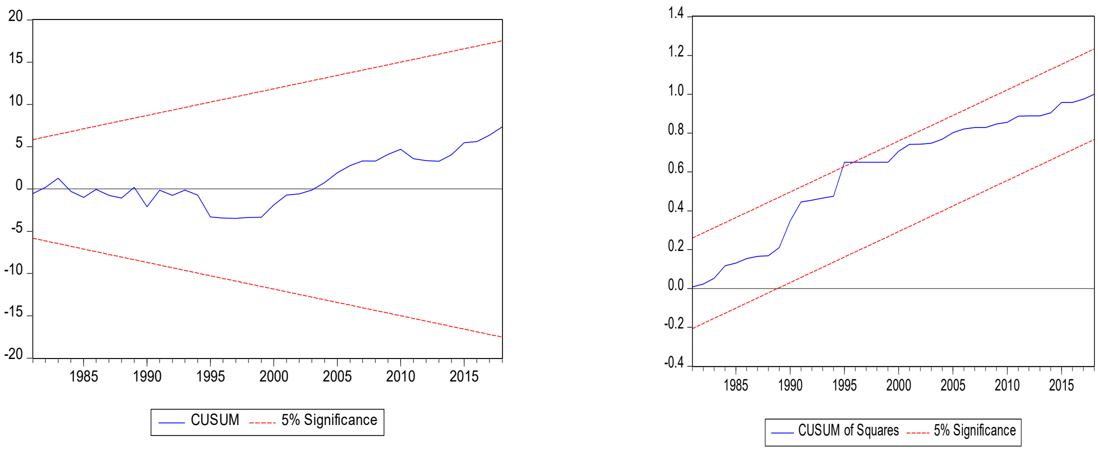

Figure 4. Stability tests.

5. Conclusions and policy implications

This paper examined the long-run relationship between per capita CO_2 emissions, real GDP per capita, energy consumption per capita and financial development based on the environmental Kuznets hypothesis for Tunisia over the period 1970 to 2018. In the current study, this model was examined by applying the Autoregressive Distributed-Lag modelling approach to cointegration analysis and error correction models (ECMs) developed by Pesaran *et al.*[58]. The bounds testing approach to cointegration yields a proof of a long-run relationship among variables.

The empirical findings show a positive monotonic relationship between CO_2 emissions and real GDP (negative and positive coefficient of real output (GDP) and the square of real output (GDP^2) respectively were found in Equation (1)). Therefore, we conclude that our empirical findings do not support the EKC hypothesis in Tunisia. The error correction estimates established that error correction term coefficient is negative (−0.95) and statistically significant, which confirms of the long-run equilibrium relationship between variables. The empirical results of the ARDL technique shows that energy consumption and financial development have significant and positive impact on CO_2 emission and statistically significant. Empirical findings confirm, in the long-run, the positive direct effect of financial development on environmental degradation. Indeed, development of the financial system can positively affect environmental degradation through various channels, such as the growth channel, the energy demand canal, or the income inequality measures. As a result, those channels can stimulate manufacturing activities which gives rise to more energy demand and therefore leads to more pollution in the process.

To complement the findings of ARDL analysis, we also perform the Toda-Yamamoto Granger causality test. In this orientation, some recommendations from the causality test can be addressed to the policymaker. In the framework of energy use management, economic growth and energy consumption present a bidirectional causality, whose result is the same as that of Shahbaz and Lean[64], and Stern[87]. These results are helpful for us to appreciate the role of energy power in the process of improving economic growth: energy is an indispensable catalyst of economic activity. Certainly, an increase in energy consumption can be observed as a major sign to build a sustainable economic growth, but the shortage of energy production may restrain the economic growth of our country. These results show also that an increase in GDP cause an increase in energy consumption. It implies that environment friendly policies (energy efficiency, energy saving policy) have no adverse effect on domestic economy growth, and so the public administration can take advantage of demand-side policies to control energy consumption to reduce greenhouse gas in response to the challenge of climate change.

Causal analysis shows that in the long run, GDP cause CO_2 emission. This result also supports some other empirical research that examine the association between economic growth and environment degradation[45,62,88]. This study shows that the main drivers of carbon emissions is economic growth. As a policy proposition, the Tunisian government should reduce the usage of conventional energy used in the production process. They must further provide motivations in the form of supports and subventions for the adoption of low carbon technologies. This low can aid significantly diminish greenhouse gas emissions, promote access to energy and enhance energy intensity. Furthermore, the employment of these technologies would advantage small businesses, and create more jobs, particularly in rural zones where energy infrastructure is not sufficiently established. Additional strategies must be taken to develop stronger clean technology innovation ecosystem across the public and private sectors that encourages the adoption of low carbon technologies.

Energy consumption has a negative relationship to environment degradation, which means that an increase in the energy consumption will lead to an increase in amount of carbon dioxide in the atmosphere and environmental deterioration in the long-run period. Many academic research[63,66,68,72] specify that the relationship between energy consumption and carbon emissions is expected to be positive, since a higher level of global energy demand should result in greater economic activity can stimulate CO_2 emissions which leads to an environmental damage.

Facing both energy constraints from the supply side and demand management policies, the Tunisia government must ameliorate the power source structure to meet with the energy demand and the environment protection requirement. In order to cope with the dilemma of promoting economic growth and pollution and environmental degradation, the policy makers should:

- Sustain the independent power production (IPP) to increase investment in the renewable energy and clean technology;
- Develop better coordination mechanism between the energy regulator and domestic/regional market structure such as "The Euro-Mediterranean Energy Market Integration Project";
- Reenforce the energy efficiency policies and programs of saving energy that can help to implement projects or system of production of goods and services.

This goal can be achieved through the implementation and integration of new technologies to optimize the energy efficiency and through reinforcing environment regulation. Improving the quality of financial intermediation also reduces financing cost and can channel more funds into environmentally friendly policies. Development in the financial sector may encourages carbon trading activities that will cut off CO_2 emissions, which helps control the emission of harmful air pollutants. These results recommend several progressions of action in order to reduce the effects of financial development on the environment. Policymakers' interventions should undertake strategies that are energy-efficient. Especially, the government must encourage the use of renewable energy (solar, hydroelectric, wind, photovoltaic power plants, biomass, and geothermal power) and the implementation of energy-saving technology.

Another future papers for investigating the dynamic effects of economic policy uncertainty (EPU) and political stability (PS) on environmental degradation for the Mediterranean countries or MENA region by using other variables that influence environmental pollution, such as urbanization, and trade openness. We hope that this analysis will be more useful for policy-makers to sharpen the focus on environmental issues for the betterment of human lives by saving energy and reducing environmental degradation, which is significant for developing new renewable strategies to promotes economic growth and environmental sustainability achieving green development through the integration of policies that connect the environment, the finance and the society.

Author contributions

Conceptualization, NC and HG; methodology, NC; software, HG; validation, NC and HG; formal analysis, writing—original draft preparation, NC and HG; writing—review and editing, NC and HG. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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