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Impact of GDP growth on the ecological footprint: Theoretical and empirical evidence from Saudi Arabia

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ABSTRACT

This study aims to examine the hypothesis of the environmental Kuznets curve (EKC) within the context of Saudi Arabia from 1981 to 2017. The ARDL approach is employed to estimate the relationship between ecological footprint, energy consumption, trade openness, and GDP per capita. The findings confirm that GDP per capita, trade openness, and energy consumption positively impact the ecological footprint, and reveal the presence of a feedback relationship between GDP per capita and energy consumption. The results demonstrate the empirical validity of the EKC, indicating an inverted U-shaped relationship between GDP and ecological footprint. Consequently, as Saudi Arabia's level of economic growth advances, its environmental conditions tend to improve. To further reduce the ecological footprint, Saudi Arabia is urged to substantially increase its utilization of renewable energy sources and implement a more efficient energy policy.

1. Introduction

Like capital and labor, energy is a factor of production and has a major place in economic, social, political, and environmental aspects (IEA, 2014). While it is recognized that energy has an influence on economic growth, its influence on the environment should not be overlooked. Indeed, according to the IEA (2014), the world production of energy for consumption comes from fossil fuels, and constituted in 2004 11.2 Gtoe, with 3.95 Gtoe for the world production of oil, coal with 2.8 Gtoe, natural gas with 2.4 Gtoe, 0.7 Gtoe for nuclear, against 1.2 Gtoe on average only for biomass and renewables. By this analysis, it appears that the energy produced and intended for consumption in order to create wealth emanates from fossil or non-renewable resources, qualified as polluting.

Indeed, global warming has become one of the issues of global concern that already affects all regions of the planet in multiple ways (Masson-Delmotte et al., 2021), where the relationship between human activities and their environment is addressed under the concept of sustainable development (Nordhaus, 2019). This development takes into account the interactions between the three economic, social, and ecological pillars in order to lead society to a long-term sustainable growth path. To this end, it is noted that after three years of stabilization, CO_2 emissions are on the rise again (Zhang, 2021). CO_2 is the man-made carbon dioxide responsible for just over 55% of the additional man-made greenhouse effect (a combination of different natural gases). The increase in the concentration of these different natural gases in the earth's atmosphere is also one of the factors causing global warming. Four emitting items are a primary cause of this increase in CO_2 emissions, namely: Energy supply, industry, deforestation, and transportation (Masson-Delmotte et al., 2021).

Historically, at the theoretical level, the consideration of climate change and the factors determining it has emerged since 1980, in the face of accelerating environmental degradation (Aladejare, 2022). In addition, Nordhaus (1977) analyzed the relationship between climate change and the various sectors of the economy. He would come up with the notion of a technical backstop and explain that the concentration of greenhouse gas emissions in the atmosphere was an environmental issue that should be taken very seriously. Furthermore, energy, deforestation, and agriculture are the economic activities that impact climate change. Among these activities, energy is the most predominant in the release of CO_2 emissions due to its involvement in

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economic development. Then, he launched the climate economic analysis by proposing a cost-benefit analysis (CBA) in the economic calculation. To this end, since the agreements of the Kyoto Protocol to which the countries of the Congo Basin 2 adhere, an economic scope of the carbon market will emerge, namely: Regulated and binding markets and voluntary markets by making the polluter pay carbon taxes and by making the non-polluter benefit from the carbon credits, in relation to their greenhouse gas emission quota ceiling. In the same vein, during the 2015 COP 21 in Paris, the industrialized countries discussed financing developing countries' development and implementing African countries' electrification projects where the energy transition is slow so that these countries could adapt to the different impacts of climate change in the future, as they will be most affected.

Therefore, the situation of socio-economic factors in Saudi Arabia raises several concerns. The first has to do with the rate of population growth, which is estimated at more than 35.34 million people in 2021. The second concern stems from the fact that the development of Saudi Arabia is conditioned by resource exploitation and environmental degradation. Thus, with everyone aiming for emergence, it is essential to worry about the fate of socio-economic factors and their possible effects on the climate. Yet, by adhering to the various initiatives on environmental protection, Saudi Arabia is also engaged in a renewable energy development project. Such an option may hold out hope for its economies and the fight against climate change. All these concerns are part of the problem of this article, which can be summed up in the following question: What is the impact of socio-economic factors on climate change? Thus, analyzing the nature of the impact of socioeconomic factors on climate change is the objective of this paper.

In the remainder of this article, the literature review is outlined in the second section; the methodology is presented in the third section; the presentation and interpretation of the results are in the fourth section; and finally, the five section deals with the conclusion and policy implications.

2. Literature review

A series of empirical studies were conducted to illustrate the impact of environmental degradation on trade, urbanization, and economic growth, and sometimes vice versa. However, these studies do not use the same approaches. They were based on the Environmental Kuznets Curve (EKC) hypothesis and the gravity model for some and the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) approach for others. Indeed, Zhu and Peng (2012) evaluated the effect of population change on CO_2 emissions in China from 1978 to 2008. Using the STIRPAT model, they found that the younger the population, the higher the CO_2 emissions rate. Indeed, Trotignon (2011) used a panel data gravity approach to reach the following conclusion: The restriction of CO_2 emissions measured by the evolution of carbon intensity does not penalize exports, and seems, on the contrary, to be beneficial to the competitiveness of firms on international markets. Porter's hypothesis applied to export competitiveness is observed for the samples referring to the 27 developing countries and the 16 emerging countries, and more clearly for the sample from the BICs (Brazil, India, China). The potential for internal and external economies of scale for firms, and the attractiveness of FDI associated with these large emerging markets, represent an asset in the introduction of new processes and new products that save fossil energy.

Jaunky (2011) tested the EKC hypothesis for 36 developed countries over the period 1980 to 2005. The empirical analysis based on individual countries attests that the EKC hypothesis is verified for a number of countries including Greece, Malta, Oman, Portugal, and the United Kingdom. The results also indicate that, for all countries, a 1% increase in GDP per capita results in a 0.68% increase in CO_2 emissions in the short term and 0.22% in the long term. The low long-term elasticity rejects the hypothesis of the existence of EKC but indicates that the CO_2 emissions rate stabilizes in the long term in rich countries. Menz and Welsch (2012) analyzed the population structure and CO_2 emissions in OECD countries by considering the CO_2 emissions cycle and different cohorts. Their analysis shows that the change in age structure and cohort composition has strongly contributed to the increase in CO_2 emissions rate in OECD countries.

Shahbaz et al. (2015) examined the causal relationship between several variables: Transportation infrastructure, fuel prices, energy, and CO_2 gases in Tunisia from 1980 to 2012. Achour and Belloumi (2016) used separate models for the cases of rail and road infrastructure in Tunisia, using Johansen cointegration followed by a VECM. Schlögl and Matulla (2018) found a long-term unidirectional causal link between CO_2 emissions and the consumption of road and rail infrastructure.

Saidi et al. (2018) applied the generalized method of moments on MENA panel data from 2000 to 2016. According to the empirical results, consumption generated the dynamics of economic activity. Similarly, transportation infrastructure positively and significantly impacted the economic dynamics in the sample countries. Ahmad and Du (2017) investigated the relationship between energy production, economic growth, and CO_2 emissions in Iran with additional variables such as domestic and foreign investment, inflation, population density, and agricultural land. Annual time series are used for the periods 1971 and 2011 depending on data availability. The authors conclude that energy production produces a positive effect on Iran's economic development.

Recent statistics from the Web of Science show that there were more than 570 studies on this topic in 2020, more than 706 in 2021, and 542 already in

2022, and a total of more than 6000 studies on this topic since 1991. Some of these studies and their results are presented in Table 1.

The results of empirical studies of the EKC in the literature are not unanimous. There are a number of reasons for this: The results are generally influenced by the period of study, the level of development of the economies studied, the econometric techniques used, the degree of homogeneity of the sample, the inclusion of control variables, or by the quadratic or cubic shape of the EKC model. Moreover, the literature review shows that despite the considerable literature on EKC, there are very few studies on this issue for the case of the Ivory Coast alone. Thus, our study aims to fill this gap and contribute to the existing literature.

Table 1: Summary of environmental degradation-economic growth studies

Author(s)	Methodology	Results
Grossman and Krueger (1991)	Random effects	Confirms the EKC hypothesis for suspended particulate matter (SPM) and dark matter (smoke) but not for sulfur dioxide (SO_2)
Shafik and Bandyopadhyay (1992)	OLS	Supports the EKC hypothesis for the case of SO_2 and SPM pollutants but not for per capita carbon emissions and deforestation
Selden and Song (1994)	Fixed and country-specific effects	Mixed results depend on the model shape
Grossman and Krueger (1995)	GLS	Confirm the EKC hypothesis
Soytas et al. (2007)	Dynamic OLS	Confirm the EKC hypothesis
Ang (2008)	Cointegration and VECM	Confirm the EKC hypothesis
Akpan and Akpan (2012)	VECM	Reject the EKC hypothesis
Jebli et al. (2015)	Panel cointegration techniques	Bi-directional causality between GDP and CO_2 emissions; GDP negatively affects CO_2 emissions
Inglesi-Lotz and Bohlmann (2014)	ARDL	Reject the EKC hypothesis
Jebli and Youssef (2015)	VECM	Reject the EKC hypothesis
Shahbaz et al. (2016)	ARDL	Confirm the EKC hypothesis for all 19 countries globally and specifically in 6 countries and not in 2 countries
Armeanu et al. (2018)	Pooled OLS and fixed effect	The pooled OLS supports the EKC assumption for sulfur oxides and non-methane volatile organic compound emissions; in addition, the fixed-effect estimate validates the EKC assumption for many pollutant types
N'Zué (2018)	ARDL	Rejects the EKC hypothesis. In addition, CO_2 emissions and GDP per capita are not cointegrated
Adu and Denkyirah (2019)	The fixed- and the random effect model	Reject the EKC hypothesis
Ouedraogo et al. (2022)	FMOLS and DOLS Models	Estimates show that mineral endowment worsens CO_2 diffusion in low and medium countries. Similarly, energy intensity increases CO_2 emissions for medium and high countries

3. Data and methodology

3.1. Data

The study focuses on the country of Saudi Arabia. GDP per capita is sourced from the World Development Indicators online database. GDP per capita is expressed in US dollars (constant prices) and we take its logarithm. The Ecological Footprint per capita (EFP) is used as a proxy for environmental degradation. The ecological footprint per capita is expressed in global hectare (gha) per capita. Data for FFP is obtained from the Global Footprint Network. Other variables used as control variables are the logarithm of the investment rate used as a proxy for the savings rate, the population growth rate, the level of financial development, the school enrollment rate, and the rate of economic openness, measured by the sum of exports and imports in GDP. The data cover the 1981-2017 period.

3.2. Methodology

The empirical methodology used in this study consists of three steps to determine the degree of integration of each variable. In the econometric literature, several statistical tests are used to determine the degree of integration of a variable. The tests that will be used in this study are the Augmented Dickey-Fuller (Dickey and Fuller, 1979), and Phillips-Perron (Phillips and Perron, 1988) tests. Once the order of integration of the series is known, the next step will be to examine the possible presence of cointegration relationships that may exist in the long term between the variables. This analysis will follow the cointegration test procedure of Pesaran et al. (2001), which is more efficient than the strategy of Johansen (1988) when the sample size is small and the number of variables is high. This paper follows the methodology of recent studies on the "economic growth-environmental pollution" nexus (Karaaslan and Çamkaya, 2022; Jeon, 2022) by also including energy consumption and trade openness as explanatory variables in order to test the long-term relationship, also known as cointegration, between the ecological footprint, economic growth, energy consumption, and foreign trade, and assess the validity of the EKC hypothesis.

For the present study, we opted for the ARDL (Autoregressive Distributed Llag model), also called the black box, introduced by Pesaran et al. (1999) and then developed by Pesaran et al. (2001). There are several reasons for this choice. First of all, this method is more adapted to small sample sizes. In addition, this test can be applied to non-stationary time series without the constraint of the same order of integration, unlike other tests. Moreover, endogeneity is not a problem with this method (Harris and Sollis, 2003). Applying the general form of the ARDL model on the variables of our specified model, we obtain:

$$\Delta EFP_t = \alpha_0 + \alpha_1 EFP_{t-1} + \alpha_2 GDP_{t-1} + \alpha_3 GDP^2_{t-1} + \alpha_4 EC_{t-1} + \alpha_5 TRP_{t-1} + \sum_{i=1}^{p-1} \delta_{1i} \Delta EFP_{t-i} + \sum_{i=0}^{p-1} \delta_{2i}\, GDP_{t-i} + \sum_{i=0}^{p-1} \delta_{3i}\, GDP^2_{t-1} + \sum_{i=0}^{p-1} \delta_{4i}\, EC_{t-i} + \sum_{i=0}^{p-1} \delta_{5i}\, TRO_{t-i} + \varepsilon_{1t} \quad (1)$$

$$\Delta GDP_t = \beta_0 + \beta_1 GDP_{t-1} + \beta_2 EFP_{t-1} + \beta_3 EC_{t-1} + \beta_4 TRO_{t-1} + \sum_{i=1}^{q-1} \sigma_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{q-1} \sigma_{2i}\, EFP_{t-i} + \sum_{i=0}^{q-1} \sigma_{3i}\, EC_{t-i} + \sum_{i=0}^{q-1} \sigma_{4i}\, TRO_{t-i} + \varepsilon_{2t} \quad (2)$$

where, EFP: Ecological footprint per capita, EC: Energy consumption per capita, GDP: Real GDP per capita, TRO: Trade openness ratio which is used as a proxy for trade, ε_{1t} and ε_{2t}: Error terms. $(\delta_1, \dots, \delta_5)$ and $(\delta_1, \dots, \delta_4)$ represent the short-term dynamics of the models, while those with the coefficients $(\alpha_1, \dots, \alpha_5)$ and $(\beta_1, \dots, \beta_4)$ represent the long-term relationship. To test the cointegration relationship among these variables, we use the procedure used by Pesaran et al. (2001). This procedure is based on the Fisher test. This test is actually a hypothesis test of the non-presence of cointegration among the variables (H_0) against the existence or presence of cointegration among the variables (H_1) as shown below:

$$\begin{cases} H_0: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0 \\ H_1: \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0 \end{cases} \quad \text{for model 1}$$

$$\begin{cases} H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0 \\ H_1: B_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0 \end{cases} \quad \text{for model 2}$$

The use of the Wald test or the F statistic allows us to test the significance of the lag of the variables by taking into account the constraint of an error correction model (ECM). The asymptotic distribution of this test (respectively Fisher's) is non-standardized under the null hypothesis of non-cointegration between the variables. Therefore, the calculated value of this statistic must be compared to the critical values established by the Pesaran et al. (2001) procedure to validate or disprove one of the assumptions.

Subsequently, we developed an error-corrected model (ECM) based on the Pesaran et al. (2001) procedure. The version of this ECM is in the form of Eqs. 3 and 4 below. It is based on the variables of Eqs. 1 and 2 such that:

$$\Delta EFP_t = \alpha_0 + \sum_{i=1}^{p-1} \delta_{1i} \Delta EFP_{t-i} + \sum_{i=0}^{p-1} \delta_{2i}\, GDP_{t-i} + \sum_{i=0}^{p-1} \delta_{3i}\, GDP^2_{t-1} + \sum_{i=0}^{p-1} \delta_{4i}\, EC_{t-i} + \sum_{i=0}^{p-1} \delta_{5i}\, TRO_{t-i} + \lambda ECT_{t-1} + \varepsilon_{1t} \quad (3)$$

$$\Delta GDP_t = \beta_0 + \sum_{i=1}^{q-1} \sigma_{1i} \Delta GDP_{t-i} + \sum_{i=0}^{q-1} \sigma_{2i}\, EFP_{t-i} + \sum_{i=0}^{q-1} \sigma_{3i}\, EC_{t-i} + \sum_{i=0}^{q-1} \sigma_{4i}\, TRO_{t-i} + \eta ECT_{t-1} + \varepsilon_{2t} \quad (4)$$

where, λ and η are the adjustment speeds of the parameters and ECT represent the residues obtained from the estimation of the equations of the cointegrated models.

4. Empirical results

4.1. Unit root tests

Before testing the cointegration between variables, it is important to conduct the unit root test to ensure that no variables are integrated in order 2 I (2). This is essential because the ARDL procedure assumes that all variables are integrated in the order I (0) or I (1). If a variable is considered to be I (2), the calculated F-statistics produced by Pesaran et al. (2001) can no longer be valid. In this respect, the most common and widely used test is the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979). However, Phillips and Perron (1988) proposed a nonparametric correction to the Dickey-Fuller (DF) statistics to account for heteroscedastic errors. The results of the ADF and PP unit root tests for the variables are presented in Table 2.

Table 2: Results of unit root tests

Variables	ADF		PP	
	Level	First difference	Level	First difference
EFP	-2.110	-4.354***	-2.514	-3.655***
GDP	-1.367	-3.874***	-1.354	-4.845***
TOP	-2.364**	-	-2.814**	-
EC	-1.233	-3.684***	-1.304	-4.051***

Notes: *, **, and *** indicate 10%, 5%, and 1% significance thresholds, respectively

The application of the ADF and PP unit root tests on the series studied shows that all the variables are not stationary at the level. This leads us to reject the stationarity hypothesis for all the series at the level. Since the variables are non-stationary at level, except TRO according to ADF and PP, we proceed to tests on the variables transformed into the first difference. The results reported in Table 2 show that after differentiating the variables once, all variables were confirmed as stationary. The Phillips-Perron and Augmented Dickey and Fuller tests (Dickey and Fuller, 1979; Phillips and Perron, 1988) applied to the first difference of the data series reject the hypothesis of non-stationarity for all variables used in this study. It is therefore useful to conclude that all variables are integrated into order one. Thus, no series is integrated of order two I(2) or higher, which is of primary importance for the application of the ARDL.

4.2. Test of the cointegration relationship

To test the cointegration relationship between the series, tests are required to show that the series studied have econometric properties, i.e., are not correlated with each other and that the residuals of the model are uncorrelated, homoscedastic, and normally distributed. To do this, several tests are possible, including the Breusch-Godfrey correlation test, the Ramsey Reset test, and the Jacque-Bera normality test. Therefore, in this paper, the probability of the Breusch-Godfrey correlation test obtained (0.4375) is well above 5%, which demonstrates that the series selected in the environmental equation model are not correlated with each other. Thus, the Wald test is used to test the cointegration relationship between the variables. It allows us to verify that the series in the model has a similar long-term structure. Table 3 summarizes the results of the Wald test in order to ensure the existence of a long-term relationship between the variables.

Table 3: ARDL bounds test

Models	Wald statistics	Critical value	Lower bound value	Upper bound value
		Model1		
F(EFP/GDP, EC, TOP)	5.625	1%	3.66	5.25
		5%	2.97	4.121
		10%	2.38	3.55
		Model 2		
F(GDP/EFP, EC, TOP)	5.427	1%	3.48	5.32
		5%	2.79	4.07
		10%	2.44	3.67

Note: Calculated F-statistics: 4.625 and 4.127 (Significant at 0.05 of the marginal value). Critical values are quoted from Pesaran et al. (2001)

The F-statistics calculated for the cointegration test are presented in Table 3. The Fisher statistics (F=4.625) and (F=4.127) for both models are above the upper bound for the different significance levels of 1%, 2.5%, 5%, and 10%. We, therefore, reject the H_0 hypothesis of no long-term relationship and conclude that there is a long-term relationship between the different variables, i.e., there is a cointegration relationship between them.

Eqs. 1 and 2 are used to estimate the long- and short-term coefficients of the ARDL model with an ecological footprint (EFP) per capita and economic growth (GDP) per capita as dependent variables. The long-term marginal effect of GDP, EC, and TOP on FFE is presented in Table 4. For model 1, the coefficient on the EC variable is equal to 0.651 and is statistically significant, implying that a 1% increase in energy consumption per capita would lead to a 0.651% increase in ecological footprint per capita. The positive sign of this coefficient is consistent with the work of Puntoon et al. (2022), Karaaslan and Çamkaya (2022), Wang and Jia (2022), Nan et al. (2022), Li and Haneklaus (2022), Abid and Sekrafi (2021), Abid et al. (2022), and Dabboussi and Abid (2022). On the other hand, international trade would tend to reduce polluting emissions in Saudi Arabia. Contrary to the theoretical prediction, this result indicates that trade liberalization does not necessarily result in the migration of polluting firms from developed countries to developing countries, which are less intransigent in their environmental protection policies.

Finally, the coefficient of the GDP variable is positive and statistically significant. It implies that a 1% increase in GDP per capita would lead to a 2.032% increase in the ecological footprint per capita. On the other hand, the sign of the coefficient of the GDP^2 variable is negative and statistically significant. This suggests that the hypothesis of the EKC is validated. These results agree with those of Jebli et al. (2019) who studied a group of 22 Central and South American countries, those of Zoundi (2017) who conducted their study on a group of African countries, and those of Ul Haq et al. (2016) who studied the Moroccan case. Indeed, the EKC hypothesis is generally confirmed for developed countries (Jebli et al., 2016). For model 2, the effect of trade openness is positive. Indeed, a 1% increase in this variable would generate an increase in economic growth of 0.041% which is significant. Finally, the impact of energy consumption on economic growth is significant. Indeed, an increase in energy consumption would cause an increase in the dependent variable- i.e., economic growth- of 0.475%. Furthermore, the adjustment parameters R^2 and adjusted R^2 for models 1 and 2 vary between 0.984 and 0.960, which shows that the models are well-adjusted. The estimation of the short-term relationship presented in Table 3 shows that the error correction coefficients (adjustment towards the long-term equilibrium) are significant and negative. This means that the deviation from the long-term equilibrium corrects to 64.5% and 80.7% per year for models 1 and 2, respectively. In addition, the results show that the coefficient of the error correction term ECT_{t-1} is significant, implying that the speed of adjustment in the short term to reach equilibrium is significant. Furthermore, for model 1 this term equals -0.645, which suggests that when the ecological footprint is above or below its equilibrium value, it would adjust by 64.5% per year. The coefficients of the lagged variables represent the short-term elasticities.

These are in the same direction as those of the long-term relationship. The variables (GDP and EC) have a positive effect on the ecological footprint. On the other hand, GDP per capita squared and trade openness have a negative effect on the ecological footprint. Increasing Energy Consumption by 1% increases the ecological footprint by 0.044%. On the other hand, increasing GDP per capita squared by 1% decreases the ecological footprint by 0.047%. Thus, all the variables have a significant effect except for trade openness. Thus, for model 2, this term is equal to about -0.807, which suggests that when economic growth is above or below its equilibrium value, it would adjust by 80.7% per year. Furthermore, it is worth noting that these results are contrary to those obtained by Domguia and Ndieupa (2017) regarding the effects of economic growth and trade openness on the ecological footprint. The latter found indeed a negative impact for short-term trade openness and long-term economic growth on the ecological footprint. However, these results show that the increase in the ecological footprint in Saudi Arabia is mainly and globally the result of economic growth and energy consumption.

4.3. Robustness analysis

Table 5 summarizes the long-term estimation results between the variables from the model composed of Eqs. 1, 2, and 3 using the FMOLS and DOLS methods. When the GDP variable is considered endogenous, the results indicate that there is no long-term relationship between trade openness and this variable because the coefficients are insignificant. In other words, trade openness does not have a long-term influence on the level of GDP. On the other hand, there is a positive long-term relationship between the ecological footprint and GDP. From this perspective, an increase in the level of the ecological footprint is characterized by an increase in the level of GDP. The results indicate that there is a long-term relationship between energy consumption and GDP since the coefficients are significant. In other words, energy consumption has a long-term influence on the level of GDP. Indeed, the Saudi energy sector, characterized by overconsumption of fossil fuels, is significant enough to influence industry and therefore economic growth. Similarly, when the ecological footprint variable is considered as an endogenous variable, the FMOLS and DOLS estimators indicate that there is a positive long-term relationship between the ecological footprint and energy consumption on the one hand, showing that an increase in fossil energy consumption could lead to an increase in EFP; and on the other hand, there is a positive relationship between GDP and EFP, showing that an increase in GDP, or wealth, can lead to an increase in the level of pollution in the long term. On the other hand, the coefficient of GDP^2 is negative and statistically significant, which confirms, in the case of Saudi Arabia, the existence of the environmental Kuznets hypothesis.

Finally, by these long-term methods, trade openness negatively influences the level of the ecological footprint. In order to pronounce the possible stability of the estimated coefficients, the CUSUM and CUSUMSQ tests will be performed. This test is based on the cumulative sum of the square of the recursive residuals (Fig. 1 and Fig. 2). The value of the statistic must then evolve, under the null hypothesis of stability of the long-term relationship, between two lines representing the limits of the interval.

Table 4: Long- and short-term estimation

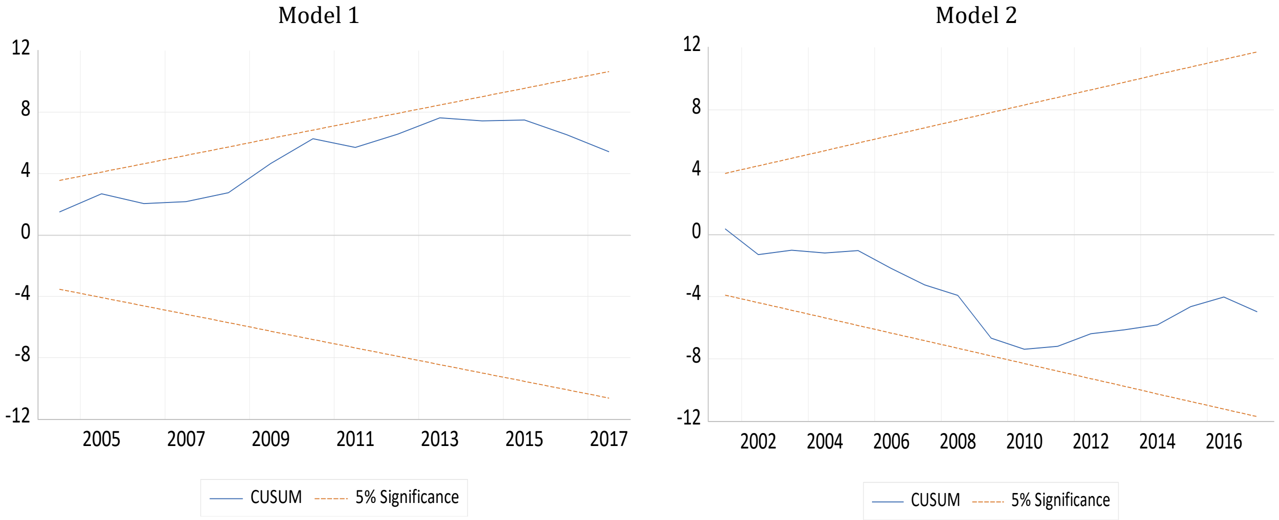
Variables	Model 1	Model 2
	Long-term	
EFP	-	0.016*** (0.001)
GDP	2.032*** (0.001)	-
GDP2	-0.008*** (0.001)	-
TOP	-0.002*** (0.001)	-0.041* (0.001)
EC	0.651*** (0.001)	0. 475*** (0.001)
	Short-term	
ΔEFP	-	0.022** (0.031)
ΔGDP	3.076*** (0.000)	-
ΔGDP2	-0.047** (0.031)	-
ΔTOP	-0.017 (0.194)	-0.055 (0.448)
ΔEC	0.044* (0.075)	0.015** (0.027)
ECTt-1	-0.645*** (0.000)	-0.807*** (0.000)
Constant	10.087*** (0.001)	12.054*** (0.000)
	Diagnostic Check	
Tests		
White	(0.489)	(0.254)
LM	(0.754	(0.373)
Ramsey-Reset	(0.124)	(0.177)
Jarque Bera	(0.366)	(0.265)
CUSUM	Stable	Stable
CUSUMSQ	Stable	Stable
R2	0.984	0.982
Adjusted R^2	0.967	0.960

Notes: *, **, and *** indicate 10%, 5%, and 1% significance thresholds, respectively

Table 5: Results of estimates of the long-term relationship by the FMOLS and DOLS methods

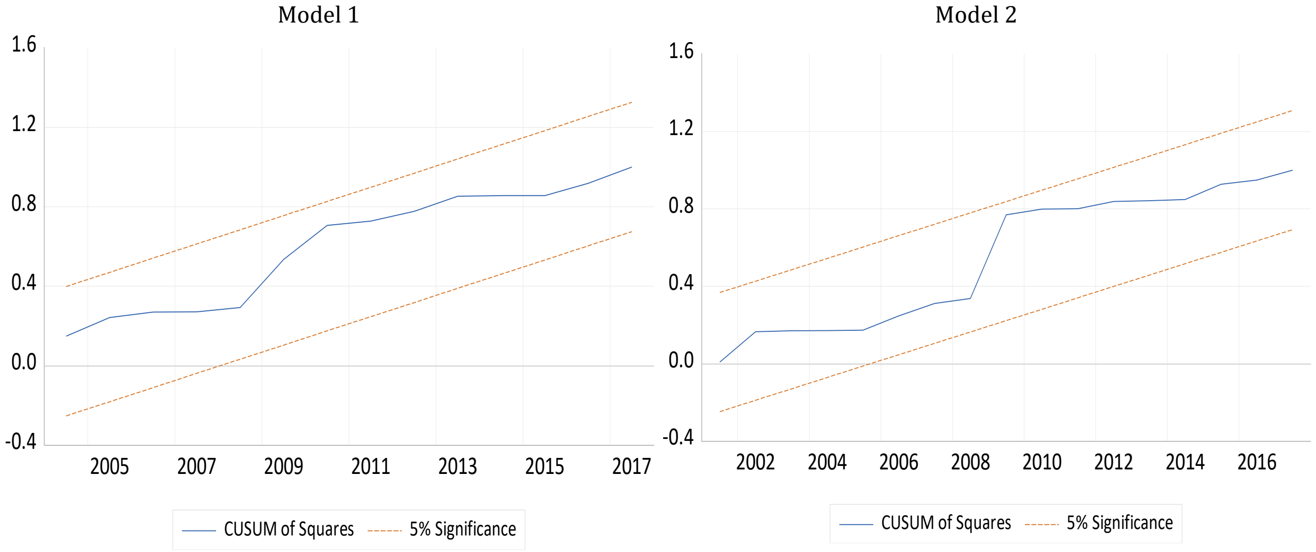
Dep. var	FMOLS	DOLS
	Model1	
GDP	3.011***	4.047**
	(0.000)	(0.033)
GDP2	-0.022**	-0.015**
	(0.014)	(0.043)
TOP	-0.007***	-0.011***
	(0.000)	(0.000)
EC	0.481*	0.615**
	(0.082)	(0.033)
	Model2	
Dep. var	FMOLS	DOLS
EFP	0.017**	0.026***
	(0.020)	(0.001)
TOP	-0.031***	-0.023***
	(0.000)	(0.000)
EC	0.350**	0.384*
	(0.025)	(0.072)

Note: ***, **, * indicate the significance at 1%, 5% and 10% thresholds, respectively


Model 1

Model 2

Fig. 1: Results of the CUSUM test


Model 1

Model 2

Fig. 2: Results of CUSUM squares test

However, the validation of the hypothesis of cointegration between the variables shows that there could be, at least, a causal relationship between them that should be verified by causality in the sense of Granger (1987), improved by Dumitrescu and Hurlin (2012). We then estimate our vector error correction model (VECM). The results globally show that there is causality between the variables in our model: First, there is unidirectional causality from energy consumption to GDP and to ecological footprint, as in Apergis and Payne (2010); second, there is unidirectional causality from trade openness to GDP confirming the results of Wang et al. (2011); and finally, there is bidirectional causality between ecological footprint and GDP.

4.4. Granger causality results

The Granger causality results are reported in Table 6. However, the most important results tend to show that for our study, there is a causal relationship between energy consumption to GDP on the one hand and a causal relationship between energy consumption to the ecological footprint on the other. These two results allow us to understand that fossil energy consumption has a significant effect, not only on economic growth but also on environmental quality in the case of Saudi Arabia. The causality effect, from energy consumption to GDP, allows us to understand that a prediction related to the increase in the level of fossil energy consumed is not without effect on the level of growth.

Table 6: Causality test

Dep. var	Source of causality				
	Short term				Long term
	ΔEFPt	ΔGDPt	ΔTOPt	ΔECt	*ECT*
ΔEFPt	–	0.141* (0.066)	-0.013 (0.451)	0.015*** (0.004)	0.011*** [4.541]
ΔGDPt	0.023*** (0.000)	-	-0.061** (0.038)	0.036** (0.017)	-0.045*** [-2.779]

Notes: Numbers in square brackets are Student's test statistics, while those in parentheses are p-values. ***, **, and * are the Significance coefficients at 1, 5, and 5% thresholds, respectively

In this context, the efforts undertaken in terms of energy infrastructure development, from available non-renewable resources, can be a way that can allow countries to increase the level of energy production and consumption conducive to industrialization. With regard to the influence of fossil energy consumption on the environment, an increase in the exploitation and consumption of non-renewable energies could have adverse effects on the environment.

5. Conclusion and policy implications

In conclusion, it is time for public policymakers to understand the theory of environmental quality evolution. This gives particular importance to the search for the form between the product and environmental degradation based on the EKC hypothesis. According to the latter, the deterioration accelerates up to a certain income level and then declines. The literature has subsequently expanded in this area. However, some studies questioned the EKC on theoretical, empirical, and methodological grounds. Indeed, the environment-income relationship can take many other forms and can have various explanations. The objective of this paper was to examine the effects of economic growth on the ecological footprint in Saudi Arabia. From time series over the period from 1981 to 2017, we applied the cointegration test by staggered lags or Autoregressive Distributed Lags (ARDL) developed by Pesaran et al. (2001) to estimate the EKC in the case of Saudi Arabia. Energy consumption and trade openness were used as control variables. These variables are all signed with the expected signs. The estimation accepts the EKC hypothesis and rejects the positive linear form. Overall, it appears that energy consumption is the main determinant of the ecological footprint. These results show that Saudi Arabia is moving towards a change in its energy consumption process to meet long-term demand as a developing country. It is necessary to have alternative solutions for the continuity of the development of industrial projects and to increase its growth and improve its socio-economic situation. Secondly, it is necessary to note the important role of economic growth in the increment of pollution. Finally, the commercial opening had a significant impact on the environmental quality.

In light of these results, some recommendations can be made. Saudi Arabia is called upon to promote renewable energies as a substitute for fossil fuels, thus boosting the economic growth rate on the one hand, but also reducing the ecological footprint and energy consumption. Therefore, it is strongly recommended to provide incentives, such as tax benefits, to encourage investment in renewable energy (clean energy), and investment in technological innovation to produce equipment that consumes less energy and emits less greenhouse gases. At the political level, these results suggest that growth objectives should be accompanied by adaptation measures. In this case, adaptation programs must be incorporated into development strategies, such as the Tunisian initiative which provides for emission limits, increased productivity, and better resource efficiency. Furthermore, Saudi Arabia must promote Inclusive Green Growth, which will necessarily go through the fight against opportunity inequalities, investments in Research and Development, raising public awareness of environmental risks, and finally, the collection and monitoring of environmental indicators.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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