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Air Pollution and Economic Development in KSA: Environmental Kuznets Curve and implications for sustainable development

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ABSTRACT

In a global context increasingly concerned about climate hazards, understanding the impact of economic growth on the environment is becoming crucial, especially for developing countries. This paper addresses this issue through the lens of carbon dioxide (CO_2) emissions and examines how economic growth affects the environment in the case of KSA. The objective of this study is to test the validity of the environmental Kuznets curve over the period 1990-2020 using the Granger causality test. The results of the test indicate a long-term relationship between the variables, and the results of the long-term model confirm the environmental Kuznets curve hypothesis for the Saudi economy with a GDP per capita turning point of US$ 19977,794. The results suggest that there is a bi-directional, short-term causal relationship. The long-term causality is unidirectional from income to CO_2 emissions. Our results suggest that the KSA should distinguish between economic policy and environmental policy to improve its environmental quality. Economic expansion leads to an increase in the level of pollution and the concentration of GHGs in the atmosphere if the government does not take the necessary precautions.

Keywords: CO_2 Emissions, Economic Growth, Johansen Cointegration, KSA
JEL Classifications: Q55, Q56

1. INTRODUCTION

Relying on the awareness of global environmental problems, especially the degradation caused by GHG emissions (particularly carbon dioxide) and the influence of economic growth on the environment, the concept of sustainable development emerged in the late 1980s and is defined as “development that allows for the satisfaction of present needs without compromising the ability of future generations to satisfy their own.” A prerequisite for sustainable development is therefore the compatibility between economic growth and respect for the environment (Ahmad et al., 2021; Rahman et al., 2021; Hussain et al., 2022). Consequently, the EKC issue falls within the framework of sustainable development. Indeed, the EKC hypothesis suggests that there is an inverted U-shaped relationship between environmental degradation and income per capita (Anwar et al., 2022; Wen et al., 2022). At the beginning of economic growth, pollution and environmental degradation will increase; then, beyond a certain level of income per capita, economic expansion will result in environmental improvement (Hussain et al., 2023; Khan et al., 2021).

The attention given to environmental issues has been growing since the first Rio Summit in 1992. It occupies a very important media space given the worrying evolution of pollution over the last five decades which is expected to continue to increase due to global energy consumption (Gill et al., 2019; Abid and Sekrafi, 2021). Indeed, climate change- mainly due to the accumulation of Greenhouse Gases (GHGs), the most important of which is carbon dioxide (CO_2)- represents the main threat to humanity today, and would cost the world economy more than 500 billion dollars if governments do not take radical measures (Stern, 2006).

Indeed, international trade is a more important factor that can account for the EKC (Liu et al., 2022). Thus, the impact of international trade on environmental quality remains ambiguous for many studies (Andriamahery and Qamruzzaman, 2022; Wu et al., 2022; Murshed et al., 2022; Dkhili, 2022; Kilinc-Ata and Likhachev, 2022; Karimi et al., 2022; Wang et al., 2022). On the one hand, international trade increases the size of the economy, which can generate more pollution (Frodyma et al., 2022). On the other hand, through the composition effect, trade liberalisation can lead to better environmental quality (Anwar et al., 2022). On the one hand, trade could play a positive role in this process by facilitating the diffusion of environmentally friendly technologies worldwide. Of course, this would require countries to be willing to remove barriers to the import of modern technologies and environmental services (Fatima et al., 2022). Trade can improve the environment through the composition effect and/or the technological effect (Udeagha and Ngepah, 2022). On the other hand, trade leads to an increase in the size of the economy which increases pollution (Pata et al., 2022). Trade is a cause of environmental degradation that could be developed through the scale effect (Haldar and Sethi, 2022).

Pollution that originates from intensive pollution production may decline in one country while it may increase in another through international trade. This compositional effect is attributed to the displacement hypothesis or the pollution haven hypothesis. According to this hypothesis, low-income countries specialize in polluting industries. Some countries become pollution havens by attracting environmentally damaging activities from developed countries through less stringent environmental regulations (Murshed et al., 2022). The observed inverted-U curve may be the result of changes in international specialization. This means that poor countries specialize in the production of purely dirty products and goods, while rich countries specialize in the production of clean goods and services (Zubedi et al., 2022). In this context, the composition effect of trade liberalization is a determinant of the EKC. Indeed, if rich countries adopt a stricter policy, the production of polluting goods is relatively more expensive than that of clean goods. Rich countries will therefore specialise in the production of clean goods and outsource polluting activities to poor countries where regulations are less strict. As a result, pollution decreases in developed countries but increases in developing countries (Liu et al., 2022). The reduction of pollution in rich countries and its increase in countries with middle-income economies may reflect the process of specialisation. According to the pollution haven theory, international trade and the associated specialisation process can explain the EKC (Abid and Sekrafi, 2021).

This choice was motivated by two observations. First, within the rich and recent empirical literature, detailed studies on economic growth and the environment in Saudi Arabia remain very scarce, despite the country's considerable efforts in environmental protection. Secondly, the relationship between GDP and environmental pollution has been the subject of several research studies in recent years, but the empirical evidence remains ambiguous to date.

The rest of the article is organized as follows: Section 2 presents the literature review; section 3 presents the methodology and data; section 4 is reserved for the analysis of the results; and section 5 presents the conclusion and some economic and environmental policy recommendations.

2. LITERATURE REVIEW

A lot has been written since the founding article by Grossman and Krueger (1991). The first empirical studies emerged such as those of (Stern et al., 1996; Ekins, 1997; Heil and Selden, 1999). These authors tested the EKC hypothesis, but revealed some contradictory results. More recently, some research has revealed a linear relationship between pollution and economic growth (Shafik, 1994; De Bruyn et al., 1998; Azomahou et al., 2006; Wang et al., 2022); while others have demonstrated an inverted U-shaped relationship (Pincheira and Zuniga, 2021; Farhani and Balsalobre-Lorente, 2020; Naveed et al., 2022). Studies have confirmed an N-shaped relationship (Shafik, 1994; Friedl and Getzner, 2003; Ren et al., 2014). In contrast, other studies have not reported any relationship (Richmond and Kaufmann, 2006; Gassebner et al., 2011).

A first field of investigation focused on the pollution haven hypothesis, revealing that (polluting) industrial activity in rich countries would outsource to poor countries where environmental regulations are less strict. In order to test this pollution outsourcing hypothesis, recent studies have considered the role of several control variables. Kearsley and Riddell (2010) studied the links between growth and the environment by introducing the explanatory variables of trade openness, the share of polluting exports and imports between OECD countries and developing countries. Their results lead them to reject the pollution haven hypothesis. However, Cole's (2004) study shows that trade openness and the share of polluting imports do have an impact on CO_2 emissions in developed countries, thus providing support for this hypothesis. Within the same analytical framework, but focusing instead on the existence of an EKC, the work of Ang (2007) for France, Jalil and Mahmoud (2009) for China, Nasir and Rehman (2011) for Pakistan, and Omri (2013, 2015) for the 12 MENA countries managed to demonstrate an inverted U-shaped curve using economic growth, CO_2 emissions, and trade. Others show that the EKC hypothesis is not valid (Ozturk and Acaravci, 2010 for Turkey; Jaunky 2010 for 36 high-income countries; Menyah and Wolde-Rufael, 2010 for South Africa; Yilanci and Pata, 2020 for China; Pata and Aydin, 2020 for 24 OECD; Massagony and Budiono, 2022 for Indonisia).

Another stream of research criticizes the functional forms used in this area and thus proposes non-parametric specifications to study the EKC. Azomahou et al. (2006) study the relationship between CO_2 emissions, energy consumption, income and foreign trade in Turkey over the annual period 1960-2005. The results reveal the existence of two forms of long-term relationships between the variables. In the first model, pollution was determined by energy consumption, GDP and foreign trade. In the second form, GDP was determined by CO_2 emissions, energy consumption and foreign trade. The results of the Granger causality tests reveal that GDP is the most important variable in explaining CO_2 emissions and is followed by energy consumption and foreign trade. Thus, they rejected the EKC hypothesis and accepted the existence of a monotonic relationship between pollution and income per capita. In this respect, Jalil and Mahmoud (2009) extend the same methodology of Halicioglu (2009) for the case of China during the period 1975-2005. A quadratic relationship (EKC) between income and CO_2 emissions was demonstrated. The results of the Granger causality tests indicate a unidirectional causality from GDP to CO_2 emissions. The empirical results also indicate that CO_2 emissions are mainly determined by GDP and energy consumption in the long term.

Following these works, Jayanthakumaran et al. (2012) demonstrate through cointegration tests for the case of China and India that CO_2 emissions in China were influenced by income per capita, energy consumption and structural changes. However, a similar causal link may not be established for India with respect to structural changes and CO_2 emissions, since India has a much larger informal economy than China. In other words, India has a high number of micro enterprises that are low energy consumers, and this economy is not competitive enough to reach international markets. Furthermore, Halkos and Tsionas (2001) analysed the same relationship using regime-switching models and also reported a monotonic relationship.

Therefore, in the standard EKC model, the introduction of additional variables can play a crucial role in determining the shape of the relationship between development and the environment. These variables include economic openness (Dogan and Turkekul, 2016; Ozatac et al., 2017; Rana and Sharma, 2019; Koc and Bulus, 2020; Bekun et al., 2021; Pata and Caglar, 2021; Kosh et al., 2021; Pata et al., 2022; Mahmood, 2022); foreign direct investment and the quality of institutions (Biswas and Dasgupta 2012; Doytch and Uctum, 2016; Usman and Jahanger, 2021; Hussain and Dogan, 2021; Singhania and Saini, 2021; Ochoa-Moreno et al., 2021; Jahanger et al., 2022; Karim et al., 2022; Nhuong and Quang, 2022); energy consumption (Zhang et al., 2017; Ozcan and Ulucak, 2021; Jena et al., 2022); and financial development (Omri et al., 2015; Nasreen and Anwar, 2015; Memduh Eren et al., 2022).

A final stream of research takes into account the evolution over time of the structure of developed countries. The idea is to introduce a composition effect into the study of the EKC. Indeed, in industrialized countries, the transition from industrialization to service production generates a decrease in carbon intensity, hence a change in the relationship between income per capita and pollution. Following Stern's (2002) decomposition model, Auci and Becchetti (2006) proposed an adjusted EKC model. The specification used in their work is the introduction of the share of coal, gas and oil used to produce electricity as well as the shares in GDP of manufacturing, agriculture and services, to take into account the structure of the economy and the effect of technical progress. However, their estimates based on a panel of 173 countries do not conclude in favor of an EKC. For this reason, it should be noted that research including additional explanatory variables and using different estimation techniques has produced conflicting results, leading researchers to revisit this topic.

3. MATHEMATICAL MODEL

The evidence for EKC was substantiated by several empirical studies. These studies share common features in terms of the nature of the data and the methods employed. The model used to test possible relationships between pollution levels and income is given by:

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + \varepsilon_{it} \quad (1)$$

Where y is the natural logarithm of the environment indicator, x is the natural logarithm of income, z represents other explanatory variables of influence on environmental degradation, ε is the stochastic error term, α is the country-specific effect, β_k is the parameter related to the explanatory variables. i is the country index and t is the year index.

The functional form of the EKC is determined by β_1, β_2 and β_3 in the Table 1 below:

For case 4, the turning point characterizing the end of the first phase of the EKC and the beginning of the second must verify the following condition:

$$\delta y / \delta x = 0$$

The corresponding value of this point must necessarily be positive. This suggests that β_1 and β_2 have opposite signs. This value is given by:

$$x^* = \exp(-\frac{\beta_1}{2\beta_2})$$

For case 6, the turning points are reached for:

$$\delta^2 y / \delta^2 x = 0$$

They correspond to the following necessarily positive income per capita values:

$$x_1^* = \exp(\frac{-2\beta_2 - \sqrt{4\beta_2^2 - 12\beta_1\beta_3}}{6\beta_3})$$

$$x_2^* = \exp(\frac{-2\beta_2 + \sqrt{4\beta_2^2 - 12\beta_1\beta_3}}{6\beta_3})$$

Several econometric studies used the model (1.1) to test for the existence of an EKC between income and environmental

Table 1: EKC's functional form

	Coefficients sign	EKC form
1	$\beta_1 = \beta_2 = \beta_3 = 0$	No relationship between x and y,
2	$\beta_1 \rangle\ 0$ et $\beta_2 = \beta_3 = 0$	Increasing monotonic relationship
3	$\beta_1 \langle\ 0$ et $\beta_2 = \beta_3 = 0$	Decreasing monotonic relationship,
4	$\beta_1 \rangle\ 0$, $\beta_2 \langle 0$ et $\beta_3 = 0$	Inverted U-shaped relationship
5	$\beta_1 \langle 0$, $\beta_2 \rangle 0$ et $\beta_3 = 0$	U-shaped relationship
6	$\beta_1 \rangle 0$, $\beta_2 \langle 0$ et $\beta_3 \rangle 0$	N-shaped relationship,
7	$\beta_1 \rangle 0$, $\beta_2 \rangle 0$ et $\beta_3 \langle 0$	Inverted N -shaped relationship,

EKC: Environmental Kuznets curve

degradation. The possible forms which the EKC can take in the cases indicated above are presented in (Figure 1).

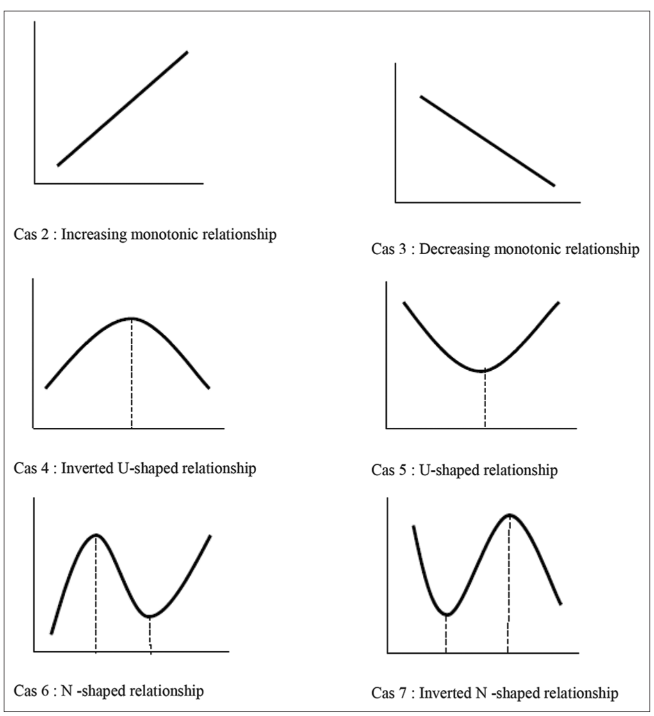
4. METHODOLOGY AND DATA

4.1. Methodology

To obtain a non-spurious econometric estimate of the relationship between CO_2 emissions and economic growth, it is obvious to have a preliminary statistical testing protocol. Thus, the determination of the direction of causality between these two series follows the following three steps:

First (i), we need to determine the order of integration of the variables. To conduct this study, we used the Dickey-Fuller (ADF) unit root stationarity test (Dickey and Fuller, 1979) and the Phillips-Perron (PP) test (Phillips and Perron, 1988). However, the ADF test only considers the presence of autocorrelation, whereas the PP test examines the presence of both the autocorrelation and the heteroscedasticity hypothesis between the variables. Once the order of integration of the series is determined, the next step (ii) examines the presence of long-term cointegration relationships between the series. The linear combination can be written as follows: $\varepsilon_t = x_t - \alpha - \beta y_t$, where α and β are constants and ε_t is a stationary process I(0) (Sebri and Abid, 2012). This analysis corresponds to the cointegration test procedure of Johansen (1988). Thus, this procedure is more efficient than the two-step approach of Engle and Granger (1987), especially for a small sample with a large number of variables. Indeed, there may be several stationary linear combinations between integrated variables of order one. In Johansen's method, the dimension of the cointegrating space is determined by estimating an autoregressive model using the maximum likelihood method. The advantage of this method is twofold: on the one hand, it can perform linear restriction tests on the cointegrating vector of parameters and, on the other hand, it can take into account several specifications: the presence or not of a constant and a trend in the long-term relationships.

Figure 1: Forms of the environmental Kuznets curve



If the series studied are cointegrated, the third step (iii) consists of estimating a VECM that integrates the variables in variation and in level. The existence of a cointegration relationship between two variables implies the presence of a causal link in at least one direction. This causal relationship can be assessed within the Granger causality test which is based on Vector Error Correction Models (VECM). According to Granger's theorem, any cointegrated system indicates the presence of an error correction mechanism (restoring force) that prevents the variables from moving away from their long-term equilibrium. The error-correction model is a special form of latent delay autoregressive models (ARDL). This model can be considered as a fitting model. At the fit model level, the coefficient of the error term is only relevant when it is significant and between −1 and 0.

In this work, the VECM is specifically adopted to determine the direction of causality in the Granger sense in the short and long terms between CO_2 emissions and economic growth per capita in KSA. Since using the VECM requires the series to be cointegrated with the same order, it is essential to, first, test the stationarity of the series. A series is said to be non-stationary if it has a mean, variance, autocorrelation and covariance independent of time and if its variance is finite. A non-stationary series must be differentiated *d* times to be stationary, then it would be integrated of order *d*: i.e., I (*d*).The stationarity step is necessary in the literature, as Granger causality tests between series are generally insensitive to this step (Stock and Watson, 1989). Indeed, when the two series are integrated of the same order, we proceed to the next step by examining the presence of cointegration. There are many possible tests for cointegration. The bivariate approach of Engle and Granger is very restrictive. It can only be applied if there is a cointegration relationship. However, the most commonly used method is the Johansen cointegration test based on the autoregressive representation discussed by Johansen (1988) and Johansen and Juselius (1990). This test determines the equations' cointegration number for any normalization used. It proposes two different likelihood ratio tests (*LR*): The first is based on the statistical trace and the other on the maximum eigenvalue.

Cointegration implies that causality exists between the two series, but it does not indicate the direction of the causal relationship. We use a VECM instead of a VAR model, since we cannot use the VAR model in the presence of cointegration. The VAR model can suggest a short-term relationship between the variables because a long-term relationship cannot be said to exist when the series are not cointegrated, whereas a VECM can avoid such shortcomings. In addition, the VECM can distinguish the long- and short-term relationship between variables and can identify sources of causality that cannot be detected by the usual Granger causality test. Dynamic Granger causality can be captured from the error-correction model from the long-term cointegrating relationship (Granger, 1988). Engle and Granger (1987) showed that if two series are cointegrated, the error correction model for the vector of CO_2 emissions and economic growth per capita can be written as follows:

$$\Delta y_t = \alpha_{10} + \sum_{i=1}^{k11} \alpha_{11i} \Delta y_{t-i} + \sum_{j=1}^{k12} \alpha_{12j} \Delta x_{t-j} + \alpha_{13} ECT_{t-1} + \mu_{1t} \quad (2)$$

$$\Delta x_t = \alpha_{20} + \sum_{i=1}^{k21} \alpha_{21i} \Delta x_{t-i} + \sum_{j=1}^{k22} \alpha_{22j} \Delta y_{t-j} + \alpha_{23} ECT_{t-1} + \mu_{2t} \quad (3)$$

Where y_t is income per capita, x_t is the CO_2 emissions per capita, μ_{1t} and μ_{2t} are error terms that follow white Gaussian noise. In addition, Δ and ECT_{t-1} are respectively the difference operator and the coefficient of the delayed error correction term. Also, α_{13} and α_{23} are the deviation of the dependent variable from the long-term equilibrium. The significance of the coefficients of the explanatory variables

$(\alpha_{12}\ \Delta x_t = \alpha_{20} + \sum_{i=1}^{k21} \alpha_{21i} \Delta x_{t-i} + \sum_{j=1}^{k22} \alpha_{22j} \Delta y_{t-j} + \alpha_{23} ECT_{t-1} + \mu_{2t}$ and $\alpha_{22})$

is mentioned as the presence of short-term causality. The VECM is used to determine the directions of causality in the short and long terms. In the short term, causality should be examined from the α_{12} variable in equation (2) and the α_{22} parameter in equation (3) using the Wald- X^2 statistic test. The x_t test does not cause y_t in the short term, and is based on the hypothesis that the sum of the α_{12j} coefficients in equation (2) equals zero. In the opposite case, when y_t does not cause x_t in the short term, we must test the nullity of the sum of the α_{22j} coefficients in equation (3); while long-term causality should be assessed from the speed of adjustment of α_{13} and α_{23} which are the ECT error correction term coefficients. The presence or absence of long-term causality can be established by studying the significance of the α_{13} and α_{23} coefficients of the error correction term in equations (2) and (3) based on the Student test. These coefficients represent the measure of the speed of adjustment towards equilibrium. Finally, we can also check whether the two sources of causality are jointly significant by testing the joint hypothesis (using the Fisher test) of $\alpha_{12} = \alpha_{13} = 0$ in equation (1) and $\alpha_{22} = \alpha_{23} = 0$ in equation (3). The rejection of the joint hypothesis indicates that, after a shock to the system, these two sources of causality are responsible for restoring the long-term equilibrium as in the studies of Abid (2020) and Sebri and Abid (2012).

4.2. Data

Our empirical study was conducted using a time series over the period 1990-2020. GDP is expressed in constant US dollars based on the year 2015. CO_2 emissions are expressed in metric tons per capita. Data is obtained from the World Bank (World Development Indicators). For scale reasons, we use the natural logarithm of these variables. (Table 2) presents the descriptive statistics on the variables used in our study. Thus, we can note that during the period 1990-2020, the average GDP was 9.80 with an annual variation of 0.06. CO_2 emissions were on average 2.58 with an annual variation of 0.15.

(Figure 2) examines graphically the evolution of Gross Domestic Product and CO_2 emissions during the period 1990-2020. We can observe that these variables show similar long-term evolutions and are characterized by a general upward trend.

This suggests that there may be an equilibrium or cointegration relationship between both GDP and CO_2 emissions. The correlation between these variables is 0.90. This value, close to 1, shows that CO_2 emissions are strongly correlated with GDP.

5. EMPIRICAL RESULTS

The results of the regressions of the relative EKC in KSA reported in (Table 3) show the insignificance of the parameter relating to the variable GDP in the cube. The estimation of a relative quadratic relationship shows the significance of the parameters of the explanatory variables at the 1% threshold. Therefore, we decide to study a quadratic equation that accounts for the CO_2 emission per capita as a function of the income per capita.

The estimation results of equation (1) reveal other interesting results regarding the signs of the parameters. These coefficients alternate signs, which confirms the EKC hypothesis. This assumption suggests that the coefficient on income must be positive while it is negative for income squared. This form recapitulates the environmental degradation: at the beginning of economic growth, pollution will increase; then, beyond a certain level of income per capita, the calculated turning point is \$19977,794 in 2015, the economic expansion will induce an improvement in environmental quality.

In order to investigate the EKC hypothesis and calculate the turning point, the next step in the analysis is to test for the presence of unit root and cointegration relationships between the variables.

Table 2: Descriptive statistics and correlation matrix

Variables	CO_2	GDP
Mean	2.580	9.805
Median	2.559	9.800
Maximum	2.848	9.902
Minimum	2.371	9.649
SD	0.154	0.062
Skewness	0.251	−0.370
Kurtosis	1.595	2.612
Jarque-Bera	2.877	0.902
Probability	0.237	0.636
Observations	31	31
Pearson's correlation tests		
CO_2	1	
GDP	0.907*** (0.002)	1

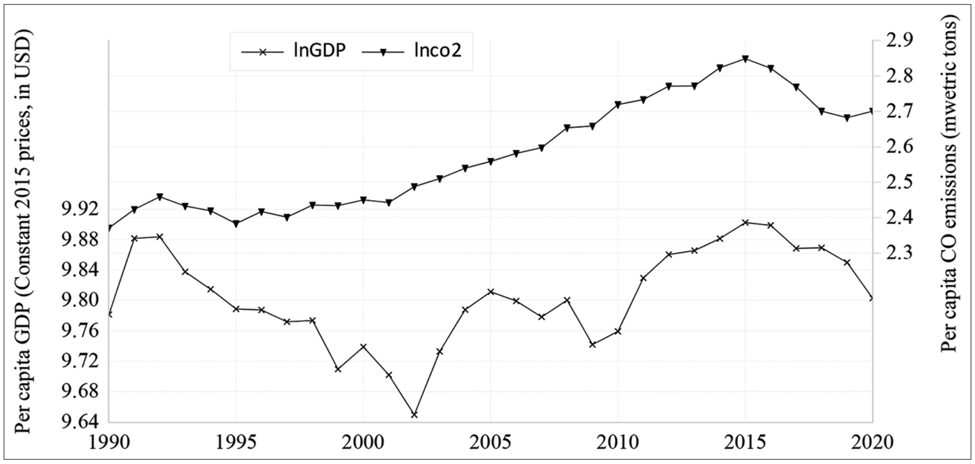
GDP: Gross domestic product

Table 3: EKC regression results

Dep. Var	Cubic specification	Quadratic specification
Variable	Coefficient	Coefficient
β_0	−0.669 (0.962)	−10.915*** (0.000)
β_1	−1.518 (0.749)	0.788*** (0.000)
β_2	0.352 (0.503)	−0.107*** (0.000)
β_3	−0.017 (0.377)	
R^2	0.9452	0.9451
$\bar{R}^2$	0.9433	0.9433
n	31	31

***Is the 1% critical level. Values in parentheses are P-values. EKC: Environmental Kuznets curve

Figure 2: Evolution of gross domestic product and CO2 emissions per capita from 1990 to 2020



Data source: World Development Indicators (WDI, 2023)

The estimation of the relationship between the variables requires first of all the knowledge of the order of integration of the series in order to escape from I (2) variables and thus avoid falling on spurious estimates. To do so, we rely on the unit root test at the logarithm of the variables in level and first difference. The results of the Augmented Dickey-Fuller (ADF) (1979) and Phillips and Perron (1988) unit root tests are detailed in (Table 4).

We note that economic growth and CO_2 emissions are integrated of order 1 (I[1]). Using the Akaike criterion to select the optimal lag, it appears that the optimal lag for our model is 2. As soon as the series are integrated of the same order, we look for a cointegration relation between economic growth and CO_2 emissions using the method proposed by Johansen (1991). (Table 5) below shows the results of the cointegration test:

This table shows that the null hypothesis (of at most) r = 0 (for the trace test) or exactly r = 0 (for the maximum eigenvalue test) is rejected at the 5% threshold. This is because the values calculated from these two statistics (27,508 for the trace statistic and 21,867 for the maximum eigenvalue statistic) are higher than the associated critical values (20,261 and 15,892 respectively). On the other hand, the null hypothesis $r \leq 1$ (for the trace test) or r =1 (for the maximum eigenvalue test) cannot be rejected at the 5% threshold because both Johansen test statistics are below their associated critical values. Both Johansen cointegration tests take into account the presence of a single cointegrating relationship between economic growth and CO_2 emissions, which means that these two variables have a long-term equilibrium. Thus, it is possible to have economic growth with an equivalent increase in CO_2 emissions, just as it is possible to have an increase in CO_2 emissions that affects growth.

Indeed, the robustness of the VECM is assessed using the Jarque-Bera residual normality test, the Portmenteau auto-correlation test, the autocorrelation test, and the White homoscedasticity test (Abid, 2020). Using the Portmenteau autocorrelation test, the Box-Pierce and Ljung-Box Q-statistics are equal to 30.83 and 41.06, respectively. Thus, we accept the null hypotheses of the non-correlation of the series up to a lag number of 12. In

Table 4: Unit root tests

Variables	ADF		PP	
	In level	In first difference	In level	In first difference
GDP	1.99 (0)	−5.22 (0)*	3.348 [6]	−5.237 [2]*
CO_2	0.174 (1)	−8.361 (0)*	0.914 [27]	−11.716 [14]*

*denotes significance at 1%. The optimal number of lags for the ADF test is chosen using AIC and "Bandwidh" for the PP tests. The critical values for the ADF and PP tests are obtained from MacKinnon (1996). The figures in brackets are the delay levels based on the Schwarz information criterion. The figures in square brackets represent the automatic selection of Newey-West bandwidth using the Bartlett kernel. Note that only the constant is included in the tests

addition, the LM autocorrelation test indicates that we accept the null hypotheses of the uncorrelation of the series up to a lag number of 12. The Jarque-Bera test statistics for normality of the residuals are, respectively, equal to 1.63 and 2.07 in equations (1) and (2) and indicate that we accept the null hypothesis of normality of the residuals. The joint White homoscedasticity test statistic (cross product terms are absent[1]) is 28.54, with a probability of 0.054, which indicates that we accept the null hypothesis of non-heteroscedasticity at the 5% confidence level. Therefore, the residuals of the model can be described by a white Gaussian noise process.

Indeed, the estimation of the VECM provides the following cointegration vector (1, −1.728, 3.756). We have normalized the cointegration equation by taking into account the *ECT* coefficient. The results of the estimation of the VECMs are reported in Table 6. They show that the error correction term is statistically significant at the 5% threshold in the second equation of the VECM. The error correction terms have negative signs except for the first equation. The coefficient of the error correction term is interpreted as the speed of adjustment (η) which measures the speed with which a variable returns to the long-term equilibrium level. The estimated coefficients have signs consistent with the VECM theory. These represent the recall force or feedback force of the considered variables.

1 If cross product terms are absent in the White test, it is a pure heteroscedasticity test.

Table 5: Johansen cointegration tests

Model	Eigenvalues	H_0: r^a	Trace	λ-max	Critical values at 5%.	
					Trace	λ-max
(GDP, CO_2)	0.542	0	27.508	21.867	20.261	15.892
	0.182	1	5.640	5.640	9.164	9.164

r^a indicates the number of cointegrating relationships. Critical values for the maximum eigenvalue and trace test statistics are proposed by Johansen and Juselius (1990). We assume that the data do not have deterministic trends and that the cointegrating relationships have constants

Table 6: VECM estimation results

Model (retard)	Estimated coefficients of lagged explanatory variables					
	y_{it-1}	y_{it-2}	x_{it-1}	x_{it-2}	ECT	Constant
Eq1 (2)	0.049 (0.336)	−0.027 (0.587)	0.110* (0.004)	−0.037 (0.244)	−0.001 (0.546)	0.007 (0.307)
Eq2 (2)	0.168* (0.006)	0.009 (0.869)	−0.009 (0.830)	−0.081** (0.033)	−0.183* (0.000)	0.021* (0.002)

(*), (**) and (***) are significant coefficients at the 1%, 5% and 10% thresholds, respectively. P-values are in parentheses. VECM: Vector error correction models

Table 7: Causality test results

Dep. Var	Source of causality (independent variable)				
	Short term		Long term ECT_{t-1}	Joint test	
	Δy	Δx		$\Delta y, ECT_{t-1}$	$\Delta x, ECT_{t-1}$
Δy		8.36* (0.004)	−0.6 (0.546)		4.57** (0.011)
	7.75* (0.005)		−7.30* (0.000)	30.08* (0.000)	

(*), and (**) are significant coefficients at the 1%, 5% thresholds. P-values are in parentheses. Δy and Δx are the growth rates of income per capita and CO_2 emissions per capita, respectively

(Table 6) reveals other interesting results regarding short-term elasticities. The elasticity of income with respect to CO_2 emissions is 0.11, while that of CO_2 emissions with respect to income is 0.168. Thus, we have a short-term bidirectional causality between income and emissions. A shock to the value of CO_2 emissions per capita leads to a shock to income per capita, and vice versa. However, a sudden drop in the growth rate (emission) not only causes an immediate negative shock to the growth rate of the emission (income), but also the effect will persist because of the significant lag that determines CO_2 emissions growth rate.

According to equation (Eq1) of the VECM, the speed of adjustment is 0.1% whereas it is 18.3% in equation (Eq2). The shocks to income growth rates and CO_2 emissions are corrected to 0.1% and 18.3% respectively by the "feedback" effect. This implies that an deviation from the long-term equilibrium of the value of the CO_2 emission growth rate tends to accelerate rapidly to adjust to the shock and return to its equilibrium level compared to the economic growth rate.

Finally, the last step in this analysis is to determine the nature and direction of causality between the two variables income per capita and CO_2 emissions per capita. The study of causality in a VECM context is possible since the two series considered were found to be cointegrated. Thus, the EKC hypothesis assumes that the causal relationship between income and environment is unidirectional, where income causes pollution in the sense of Granger. The sources of causality can be identified from the significance test of the independent variables' coefficients in the VECM (Table 7). For short-term causality, we can test the nullity of the parameters related to the independent variables in each VECM equation using the Student's t-test. Long-term causality can be tested by the significance of the speed of adjustment. We need to test the nullity of the coefficients of the error correction terms in each of the VECM equations. Finally, we use the joint test to test for strong causality, where the variables carry the short-term adjustment overload to restore the long-term equilibrium as in the studies by Lee (2005), Mahadevan and Asafu-Adjaye (2007) and Chen et al., (2007). The results show that the error correction term is statistically significant at the 5% level in the second VECM equation. The error correction term *ECT* has negative signs except for the first equation. The coefficient of the error correction term is interpreted as the speed of adjustment, which measures the rate at which a variable returns to the long-term equilibrium level. The estimated coefficients have signs consistent with the VECM theory. These represent the recall force or feedback force of the variables considered.

6. RESULTS INTERPRETATION

Table 2 shows that despite the very high levels of income per capita in the KSA, which has very high oil revenues, it does not have the income per capita conditions to pass the turning point unless its environmental quality improves and CO_2 emissions decline. In other words, higher income may be a necessary condition for sustainability concerns to start taking over more immediate economic and social concerns and more long-term sustainability issues. Yet, it is not sufficient to prevent environmental degradation and reduce pollution. It should also be noted that nothing written in the studies of the EKC hypothesis suggests that increased income will surely lead to environmental improvement.

One interpretation is that the KSA is located in the first phase of a U-shaped curve where economic growth is accompanied by an increase in pollution. We recall at this point that the most effective factor in improving environmental quality is the rigidity of environmental policy, namely: the imposition of environmental taxes or regulations on polluters to induce firms to adopt more environmentally friendly methods, the spread of anti-pollution technologies such as the most advanced equipment, and unlimited political and civil liberties.

One factor that could explain the inverted U-shape of the EKC is the structural transformation inherent in the development process. The development process can be summarized as follows: In the first stage, the economy is essentially agricultural due to the lack of technological innovation (the scale effect). An increase in economic activity has a negative effect on the environment. If the country is endowed with natural resources, the next step may be to extract these resources and undertake their initial processing. This first phase of transition is likely to be driven by global demand and perhaps facilitated by foreign investment. Then, the economy may gradually move towards simple manufacturing (composition effect), such as textile and clothing industrial manufacturing, and then more complex manufacturing as the country gains experience and the education level of the population increases. The last phase (technical effect) is the post-industrial society, in which high technology and services dominate. Such a development would gradually change the pollution intensity and the composition of national production, so that some environmental indicators will eventually improve.

Several studies such as Shafik (1994) and Holtz-Eakin and Selden (1995) consider that the EKC profile looks like an N rather than an inverted U for many environmental indicators, especially GHGs, including CO_2. However, it is possible that at an even higher level of income, pollution starts to decrease again and the N-curve turns into an M-curve as a new generation of pollution control equipment becomes available through increased production and income. Pollution would thus move in a saw tooth pattern, influenced on the one hand by the increase in the scale of economic activities and on the other hand by the fact that more advanced pollution control technologies can be implemented as the scale of production increases. Furthermore, we mention that the environmental effects of economic growth also depend on the nature of that growth. Growth that consumes more and more natural resources is clearly more dangerous for the environment than growth based on technical progress that makes it possible to save inputs and reduce emissions.

The KSA is a country characterized by an imperfect awareness of the effects of environmental degradation and by the inactivity of NGOs, which have a crucial role in the fight against pollution. In order to promote investment and maintain employment and production, the KSA strongly encourages FDI and the outsourcing of foreign dirty industries. At the same time, economic agents do not care much about global warming and climate change. They would rather accept the consequences than pay the price of reducing emissions. This suggests that the EKC hypothesis does not depend so much on income levels per se, but rather on the institutional and demographic reforms that tend to accompany rising incomes and that are necessary to enable citizens to express their demand for environmental quality and to influence the political process. Rich countries therefore specialize in the production of clean goods and look for "pollution havens," countries where environmental regulation is either poorly developed or poorly enforced (Lucas et al., 1992). As a result, pollution is decreasing in developed countries while it is increasing in developing countries.

The results of the causality tests between income per capita and carbon dioxide emissions per capita in (Table 7) corroborate the existence of a short-term bidirectional causality. As for the unidirectional causality, the short-term causality is from CO_2 emissions to income, while the long-term causality is from income to CO_2 emissions. Generally, based on the joint test, we can see a bidirectional causality between per capita income and per capita CO_2 emissions at the 5% error risk.

The short-term bidirectional causality reflects the dependence between economic growth and CO_2 emissions growth. One movement of economic growth or growth in CO_2 emissions will affect the other. In this context, economic growth is a direct result of the accumulation of obsolete industries migrating from developed to developing countries. Indeed, some low-income countries such as most MENA countries are becoming pollution havens. These countries attract environmentally damaging activities from developed countries through less stringent environmental regulations. The main goal through this policy is to provide a high rate of economic growth that leads to rapid growth in production and improved living standards. At the same time, they fail to preserve the environment and to respect the ecological side by draining natural resources, especially non-renewable ones.

The relative short-term causality is unidirectional, from CO_2 emissions to income. It shows that growth in CO_2 emissions drives economic growth. In other words, high growth in CO_2 emissions tends to achieve high economic growth in the short term. For this economic reason and in line with the theory of the pollution haven hypothesis, Birdsall (1992) proves that EU countries try, through the exploitation of their partnership with other groups such as MENA countries, to outsource obsolete industries and polluting activities in order to ensure both a sustainable economic growth and a luxurious environmental quality.

The long-term causality is unidirectional. It goes from income to CO_2 emissions. This direction of causality shows that economic growth is the driving force behind the growth of CO_2 emissions. Furthermore, economic growth is responsible for the growth of CO_2 emissions and for the occurrence of corrosive consequences to human health such as global warming. Very high-income countries risk the re-emergence of pollution in the long term. This situation is avoided when new technologies and effective pollution control equipment are available. Very high-income countries risk the re-emergence of pollution in the long term. This situation is avoided when new technologies and effective pollution control equipment are available. This conclusion can help policy makers to reduce pollution around the world, which is normally the result of serious and strict environmental policies. The KSA is required, on the one hand, to encourage environmentally friendly industries, adopt new pollution control technologies, and honor its commitments under international environmental protocols such as the Kyoto Protocol. On the other hand, it has to minimize carbon dioxide emissions which are one of the primary sources of the global warming phenomenon.

The different estimation results between long-term and short-term causality imply the separation between economic and environmental policy. This disagreement between the two policies contributes to undermining the importance of the notion of sustainable development. A condition for sustainable development is therefore the compatibility between economic growth and respect for the environment. This compatibility is mainly illustrated by the encouragement of clean and environmentally friendly industries, the support of new energy sources and the protection of renewable energies.

7. CONCLUSION AND POLICY IMPLICATIONS

This paper aims to empirically study the profile of the EKC depending on the levels of CO_2 emissions and income per capita in the case of KSA. On the other hand, it will inspect the direction of short- and long-term causality between the variables considered. To achieve our objective, we used annual data for 31 years from 1990 to 2020. We adopted a multi-step procedure, including stationarity tests via cointegration tests and the determination of long-term adjustment speeds via VECM estimates.

First, our empirical results demonstrate the existence of an inverted U-shape curve for the case of KSA. This shape shows that pollution increases when a country emerges from poverty, stabilizes when it reaches a middle-income level and then decreases when it becomes more prosperous. The appearance of an inverted U-curve is not a spontaneous result of economic growth perse, but rather relies on the existence of strict environmental institutions and policies. This conclusion is in line with the theoretical and empirical foundations of the EKC founders Grossman and Krueger (1991). It seems that raising the level of income per capita is not the only way to combat environmental degradation. Environmental degradation only materializes in combination with other factors such as trade openness, political instability, democracy and corruption.

Secondly, the unit root tests of Dickey and Fuller and Phillips and Perron unanimously show that the GDP per capita and CO_2 emission per capita series are not stationary in level. However, their first difference is stationary. These series are therefore integrated of the same order 1. After having established the order of integration of the series, we examined the presence or not of long-term relationships between them. To do so, we used Johansen's cointegration tests. However, their first difference is stationary. These series are therefore integrated of the same order 1. Having established the order of integration of the series, we examined whether or not there were any long-term relationships between them. We used Johansen cointegration tests for this purpose. The results of the test indicated the rejection of the null hypothesis of no cointegration relationships. There is at least a long-term relationship between GDP per capita and CO_2 emissions per capita. The estimation results of the causality tests reveal other interesting results. For the short-term causality between income and CO_2 emissions, the results suggest that there is a bidirectional causal relationship. For the long-term causality, it is unidirectional from income to CO_2 emissions. The distinction between economic policy and environmental policy must have a negative impact on the environment. An economic expansion leads to an increase in the level of pollution and the concentration of GHGs in the atmosphere if governments do not take the necessary precautions.

7.1. Recommandations

Furthermore, we recommend that the KSA should promote inclusive green growth, which will necessarily involve the fight against the consumption of fossil fuels (mitigation policy), investment in research and development (innovation policy), raising people's awareness of the environmental risk issue (participation and adaptation policy) as well as the collection and monitoring of environmental indicators in all of the country's economic zones. In addition, the country should institute the use of natural gas, biofuels from waste, renewable energies (hydraulic, solar) to meet the energy needs (heat, lighting and electricity) of industry and urbanization. Finally, we recommend the strengthening of local rules relating to international openness (particularly to imports and foreign direct investment) as well as the diversification of services by putting the environmental impacts of these at the forefront in order to maintain the reduction of CO_2 emissions.

7.2. Limitations and Future Research

This study, for instance, uses data only from annual observations at the country level. A number of other econometric techniques could also be applied to this study, such as two-stage linear regression, three-stage linear regression, GMM, NARDL, and panel smooth transition regression models (PSTR). In order to continue this research work, two avenues will have to be pursued. On the one hand, it is essential to increase the size of our sample by seeking to integrate groups of countries and to extend the time period. In our empirical work we have only used the KSA. It would be interesting to include economic groups such as CEEC and NAFTA. This extension allows us to take a complete view on the relationship between income and emission around the world. On the other hand, we can explain the effect of other control variables on the relationship between economic growth and in CO_2 emissions growth. Among these variables we can mention trade openness measured by the share of trade in GDP, the share of the industrial sector in the economy that is likely to be the source of the problem, the fuel price regime as well as the share of energy products consumption, the impact of environmental policies measured perhaps by environmental preservation expenditures and by the number of environmental NGOs and institutions in such a country. In addition, we can exploit other environmental indicators responsible for environmental deterioration such as SO_2 and NOx. Also; we can study the problem of groundwater depletion.

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