Energy Strategy Reviews 40 (2022) 100814

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Do energy consumption, urbanization, and industrialization play a role in environmental degradation in the case of Saudi Arabia?

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ARTICLE INFO

JEL classification:
F18
O44
P18
Q47

Keywords:
Growth
Energy
Environment
Causality

ABSTRACT

This study tries to explore empirically the nature of the link among energy consumption, environmental degradation, trade, industrialization, urbanization, and economic growth concerning the Kingdom of Saudi Arabia's economy for a time series of data spanning from 1971 to 2019. To investigate the cointegration, the long-run relationship, and to decide the direction of causality we apply the Autoregressive Distributed Lag and the Vector Error Correction Model technologies. Our empirical findings reveal that a rise in energy consumption and environmental degradation increases economic growth; however, energy has a significant contribution to the deteriorating environment. Besides, results show the presence of a feedback effect in the long-run among the different variables. In the short-run, energy use, trade, and urbanization, Granger causes economic growth; while growth, environment, industrialization, and urbanization Granger causes energy consumption. The Saudi policymakers must consider the leading role played by trade, urbanization, and industrialization in improving economic growth and harming environmental quality by launching efficient energy policies.

1. Introduction

As the new century dawns, the world increasingly realizes that there is a major issue in achieving such a balance between the trio energy consumption (henceforth EC), environment degradation (ED), and the maintenance of economic growth (EG). There is no doubt that all governments of the world are facing challenges, economic, energetics, social, and environmental that arise on the path of development and EG. Economic issues include the instability of the global financial architecture, the increased limit of the international economic environment under the effect of global regulations, and the acceleration of economic changes due to globalization and interdependencies between countries [1–6]. Regarding energy issues, we can mention the instability of supply and demand on a global scale, security of energy supply, and depletion of oil and gas reserves [7–10]. For the social and environmental issues, we found rapid urbanization, rising pollution, worsening climate change, atmospheric warming, depletion of natural resources, and the increase in disasters linked to extreme weather events [11–14]. These challenges threaten the ability of countries to continue their progress (sustainable development) and can undermine nationally defined development strategies. Thus, these issues are linked and reinforce or compensate for each other. Therefore, it is necessary to study these challenges to understand their ins and outs, and to develop intervention mechanisms capable of countering their negative effects [15,16].

Supporting this assertion, the Kingdom of Saudi Arabia (KSA) is not on the sidelines of these issues. The country must respond to these challenges as the first economy in the Middle East and the 18th globally with a GDP of 787 billion USD in 2018, the country contributes 50% to the cumulative GDP of the Gulf Cooperation Council (GCC) countries. Moreover, the Saudi market size stands at 33.4 million residents (including 20.8 million nationals), 60% of the GCC population. The economy is structurally dependent on oil production (3rd world producer) which represented 31% of GDP and 79% of export earnings in 2018. However, energy-related greenhouse gas emissions in KSA reached 14.59 tons of CO_2 per capita in 2018, one of the top emissions levels in the globe: 3.3 times the global average and 3% below the USA. Along the same lines, several studies [1,6,13,17–19] have shown that the universal challenge to enhance environmental quality is provoked by the speedy level of industrialization and urbanization while EG, trade liberalization (TL). However, EC have mixed impacts reliant on the

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https://doi.org/10.1016/j.esr.2022.100814
Received 10 November 2021; Received in revised form 4 January 2022; Accepted 24 January 2022
Available online 3 February 2022
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growth phase of countries. Consequently, to control environmental pollution and to achieve sustainable development (Economic + Environment), it is fundamental to investigate this link. In addition to the foregoing, this paper attempts to extend the recent literature by exploring the impacts of urbanization, TL, and industrialization with the environment-energy-growth link especially for the KSA economy from 1971 to 2019. According to what we know, there has never been an endeavor to examine this link for the KSA by considering the leading role played by urbanization, trade, and industrialization. This current paper attempts to fill this gap. To achieve this, we will apply an empirical methodology based on two important steps: Initially, we will try to explore the long-run relationships by applying the Autoregressive Distributed Lag (ARDL) bounds testing approach of cointegration. Next, we will use the Granger causality test founded on the Vector Error Correction Model (VECM). We assume that a rise in EC and EG causes expansions in ED. Besides, an increase in industrialization, urbanization, and trade generates EG and higher CO_2 emissions. For TL we expected positive/negative coefficients related to CO_2 emissions. Furthermore, we expect that the empirical findings of this study have immense importance for policymakers to understand the causes of ED and therefore for advance operative economic, environmental, and energy policies which will enhance environmental quality and conserve economic progress.

This study is divided into six main sections namely: A summary of the literature review in the second section. The presentation of data and model specification is in the third section. Section 4 provides econometrics methodology. The presentation and the discussion of the empirical findings are in the fifth section. The last section ends and makes some suggestions and recommendations.

2. Literature review

The subject of the association among EC, ED, TL, industrialization, urbanization, and EG has recently well-taken a place in the environmental and energy economics literature. Numerous studies have concentrated on various countries/regions, periods (annual, monthly, quarterly, etc.), and have integrated set of macroeconomic, environment and energy variables [1,2,4,6,15,17–25]. The empirical findings of these studies join the current literature and draw the attention of both manufacturers, government, and policymakers. However, these findings are found mixed or inconclusive due to various econometric methodological used such as the ARDL and VECM methods, the Dynamic and the Fully Modified Ordinary Least Squares (DOLS and FMOLS) approach, the STIRPAT model, the Dumitrescu-Hurlin causality test, the Augmented, the Pooled, and the Common Correlated Effects Mean Group (AMG, PMG, and CCEMG) estimators, the Nonlinear Iterative Partial Least Squares (NIPALS) approach, the Generalized Method of Moments (GMM), etc. (see Table 1). In the following passages, we will expose some earlier research linked to the topic of our investigation that may be disposed of in two parts.

The first part of the research concentrates on the linkages among EC, ED, TL, urbanization, and EG that have attracted more and more attention in recent literature. For example [20], has investigated this relationship between 10-selected Central and Eastern European Countries (CEECs) during the period 1991 to 2011. The FMOLS estimator has revealed that EC leads to ED. Besides, the VECM method has shown that there is a two-way causal relationship between ED-EG and EC-EG as well. In the case of Nigeria [35], have used the ARDL method to examine the same relationship from 1971 to 2011. The findings have indicated

Table 1
A summary of empirical research findings on EC, ED, TL, industrialization, urbanization, and EG relationship.

Author (s)	Country/Region	Period	Methodology	Empirical findings
EC, ED, TL, urbanization, and EG link.				
[26]	Panel of NIC	1971–2007	Johansen panel cointegration test/ panel VECM analysis.	One-way causality from: EG and TL to ED; EG to EC; urbanization to EG; TL to urbanization (all in the short-run).
[27]	UAE	1975–2011	ARDL and VECM technologies	Bidirectional causality among ED and electricity. EG and urbanization Granger cause ED.
[28]	EU	1992–2010	Cointegration and causality approaches	One-way causality from: EC, TL, and urbanization to ED; EG to EC; EG, EC, and urbanization to TL; urbanization to EG; urbanization to TL.
[20]	10 CEECs	1991–2011	FMOLS and panel VECM analysis.	Feedback effect among ED-EG and EC-EG.
[29]	28 provinces of China	1996–2012	GMM and ARDL	Positive effects of EC on CO_2. Trade and urbanization generate ED (only in the long-run).
[30]	USA	1960–2010	ARDL and VECM	Feedback effect among ED-EG; ED-EC; ED-urbanization; EG-urbanization; EG-TL.
[21]	Saudi Arabia	1971–2014	ARDL	EC generates ED in the short- and long-run. However, urbanization enhances the quality of the environment.
[22]	Asian countries	1980–2014	PMG approach and panel Granger causality test	Urbanization raises EC and ED. A bidirectional causal relationship between EG, urbanization and ED.
[12]	Sri Lanka	1978–2014	ARDL	Long-run association between ED, EC, EG, TL, and urbanization. EC leads to ED in the short- and long-run.
[31]	8 contiguous developing countries	1998–2011	Spatial simultaneous equations	Feedback effect among EG-ED; ED-EC; EC-EG.
[4]	Australia and Canada	1960–2015	ARDL and VECM	Bidirectional causality among ED, EG, and renewable EC.
[32]	Nigeria	1980–2016	STIRPAT model, ARDL, and the Bayer and Hanck cointegration tests	Urbanization and EC are the major drivers of ED, while trade performs the opposite.
[14]	ASEAN	1990–2016	ARDL	EG, TL, and non-renewable EC contribute to ED. Unidirectional causality from urbanization to EC.
[24]	Belt and Road Initiative countries	1991–2018	Westerlund bootstrap cointegration Dumitrescu-Hurlin causality tests	Bidirectional causal effect between EG and ED; urbanization and ED.
EC, ED, industrialization, urbanization, and EG link.				
[1]	Senegal	1980–2011	NIPALS algorithm	EC, and industrialization increase ED, while urbanization and EG decrease ED.
[17]	Turkey	1974–2013	ARDL	EG, EC, urbanization, and industrialization cause ED, especially in the long-run.
[11]	China	1970–2015	ARDL and VECM	Feedback Granger causalities exist among ED, EG, and industrialization.
[33]	30 Chinese provinces	2000–2016	AMG and CCEMG estimators	Industry expansion has a powerful impact on EG, EG pulled the ED downward. Bidirectional causality between EC and EG.
[34]	156 countries	1990–2014	GMM, CCEMG, and dynamic CCEMG	The main variables industrialization and urbanization accelerate the ED.
[19]	APEC countries	1990–2014	DSUR	Industrialization degrades the environment. Besides this, EC, urbanization, and EG enhance the level of ED. Unidirectional causality is found between industrialization and ED.
[6]	Australia	1980–2014	STIRPAT	Short-run bidirectional causality between EG, EC, and industrialization with ED.

that urbanization has an insignificant effect on ED. Moreover, EG and EC have a positive and important effect on ED. Nevertheless, TL has a negative and significant effect on ED. By using GMM and ARDL methods [29], have confirmed for 28 Chinese provinces for the period of 1996–2012 the strong effects of EC on ED. In the long-run, TL and urbanization generate ED, albeit not in the short-run. Furthermore [21], has investigated the relationship between ED, EG, EC, and urbanization in the KSA from 1971 to 2014. The ARDL finding mentions the presence of a long-run association between all variables. Moreover, in the short-run EC accelerates ED. However, the effect of urbanization on CO_2 is negative and important, which means that urban development does not generate ED. Concerning the Asian countries [22], have examined the relationships between the mains variables of this first strand for the period 1980–2014 using the PMG technique and panel Granger causality tests. The results have shown that urbanization increases EC and ED. Further, the findings confirm that there is a three-way causal relationship among EG, urbanization, and ED. By applying the ARDL approach in Sri Lanka from 1978 to 2014 [12] have confirmed the long-run relationship among ED, EC, EG, TL, and urbanization. The results have found that EC and TL generate ED. However, urbanization has strong and negative effects on ED. Recently [31], has examined the nature of causality between EG, ED, EC, urbanization, and TL in eight contiguous developing countries from 1998 to 2011 by using spatial simultaneous equations. The finding has mentioned a feedback effect among EG and ED; ED and EC; EC and EG. In their study on Australia and Canada [4], have examined the link among renewable EC, EG, TL, urbanization, and ED from 1960 to 2015. For Australia, the VECM technique has indicated that EG, TL, and renewable EG Granger cause ED (short-run); while the causal relationship is obtained between ED, EG, TL and renewable EC (long-run). Regarding Canada, the findings have shown that TL increases ED (short- and long-run), while EG and urbanization rise ED (only in the long-run). The results have also documented a bidirectional causality between ED, EG, and renewable EC. Likewise [32], has used the STIRPAT model to examine the link between urbanization, TL, EC, and ED in the case of Nigeria between 1980 and 2016. The ARDL and the Bayer-Hanck tests have confirmed the cointegration between the variables. The empirical results have revealed that urbanization and EC are the principal sources of ED, while TL does the opposite. In the case of the ASEAN region [14], have explored the same relationship with data spanning from 1990 to 2016. Findings have revealed that EG, TL, and EC strongly cause ED. Further results have shown a causal relationship from urbanization to EC [24]. have studied the same causal relationships in the economies of the Belt and Road Initiative (BRI) for the period of 1991–2018. The panel cointegration test has proved long-term associations between the main variables. The CCEMG estimator has indicated that urbanization increases ED. Moreover, the Dumitrescu-Hurlin test has shown a bidirectional causal effect between EG and ED; urbanization and ED.

We present now the second part of existing literature which concerns the relationship among EC, industrialization, urbanization, ED, and EG. For instance Ref. [1], have proposed a multivariate analysis of these relationships in Senegal using the NIPALS regression during the period 1980–2011. Empirical results have shown that EC, and industrialization accelerate ED, while urbanization and EG loosen ED. In a study that focuses on Turkey [17], has examined the same relationship for the period of 1974–2013 by using the ARDL bounds tests. Findings have revealed that EG, EC, urbanization, and industrialization have a positive impact on ED in the long-run [11]. investigated something similar for China over the period from 1970 to 2015 by employing ARDL and VECM. The long-run findings have indicated that EC, EG, industrialization, and urbanization increase ED. In addition, feedback Granger causalities exist between ED, EG, and industrialization. Based on a panel of 30 Chinese provinces [33], have explored the linkages among the variables of the second group over the period from 2000 to 2016 by employing an AMG estimator as well as a CCEMG estimator. Urbanization has a mixed effect on EG (varied from negative to neutral to positive). Besides, industrialization has a strong effect on EG and therefore EG pulled the ED downward. As well, bidirectional causality between EC and EG. In their research [34], have instigated the impacts of urbanization and industrialization on ED for 156 countries over the period 1990–2014 by applying GMM, CCEMG, and dynamic CCEMG estimation procedures. The results have shown that the main variables contribute positively and significantly to ED. Additionally [19], have explored the same relationship in the APEC countries from 1990 to 2014 with the DSUR. The empirical findings have revealed that industrialization degrades the environment. It is also observed that the EC, urbanization, and EG enhance the ED. Moreover, unidirectional causality has been found between industrialization and ED. More recently [6], have investigated the effects of several indicators such as EG, TL, industrialization, EC on ED in Australia with data spanning from 1980 to 2014 by using the STIRPAT model. The findings have shown short-run bidirectional causality prevails between EG, EC, and industrialization with ED. Remarkably, industrialization development does not generate ED.

3. Data, model specification and methodology

3.1. Data

To figure out the link between EC, ED, TL, industrialization, urbanization, and EG several measures are used. This study measures economic growth (EG) as Gross Domestic Product (GDP) per capita (constant 2010 US$). Energy consumption (EC) measures energy use (kilograms of oil equivalent per capita). Environmental degradation (ED) denotes carbon dioxide (CO_2) emissions (metric tons per capita). Trade liberalization (TL) indicator of the degree of integration of a country in the world economy. The way to calculate it is to take the average of exports and imports divided by GDP. Industrialization (Ind) measures industry, value-added (percentage of GDP) divided per capita. A demographic phenomenon resulting in a tendency towards the concentration of the population in the cities. Otherwise, it affects both the increase in urban population and the expansion of cities. The data on EC, ED, TL, industrialization, urbanization, and EG have gathered from the World Development Indicators [36] online database. This research paper investigates the relationship among EC, ED, TL, industrialization, urbanization, and EG in the case of the KSA economy with data spanning from 1971 to 2019. The period of the present paper has been appointed on the accessibility of data (see Appendix 1).

Furthermore, Table 2 presents the descriptive statistics of our time-series data concerning the KSA economy. The results reveal that all variables are normally distributed as exposed by statistics of the Jarque-Bera test [37]. Pairwise correlation analysis reveals that EC, ED, TL, industrialization, urbanization, and EG are positively associated.

3.2. Model specification

The principal aim of our research paper is to explore the determinants and the type of relation between EC, ED, TL, industrialization, urbanization, and EG for the KSA economy. The association among these main variables has long been examined concurrently [38,39] and [6,14,40]. To search for the link between EC, ED, TL, industrialization, urbanization, and EG, the current paper proposes the succeeding equation:

$$EG = f(EC,\ ED,\ TL,\ Ind,\ Urb) \tag{1}$$

Following [39] this present research specifies the association among EC, ED, TL, industrialization, urbanization, and EG in the single multivariate structure, accordingly our econometric model is stated as bellows:

$$EG_t = \alpha_0 + \alpha_{1t}EC_t + \alpha_{2t}ED_t + \alpha_{3t}TL_t + \alpha_{4t}Ind_t + \alpha_{5t}Urb_t + \varepsilon_t \tag{2}$$

This last model above is converted to log-linear functional form and specified as follows:

$$lnEG_t = \alpha_0 + \alpha_{1t}lnEC_t + \alpha_{2t}lnED_t + \alpha_{3t}lnTL_t + \alpha_{4t}lnInd_t + \alpha_{5t}lnUrb_t + \varepsilon_t \quad (3)$$

where lnEG is the natural log of real GDP per capita (constant 2010 US $). lnEC corresponds to the natural log of energy consumption per capita (kg of oil). lnED is the natural log of CO_2 emissions per capita (metric tons). TL relates to the natural log of trade liberalization. lnInd measures the natural log of manufacturing value-added per capita. lnUrb is the natural log of the percentage of the urban population in the total population. α_0 represents the fixed country effect. t is the time (yearly data spanning from 1971 to 2019). ε denotes the error term. Econometrically, taking the log of variables that are already in percentage is wrong. A log of a variable is equivalent to the growth of the variable. Hence variables like trade liberalization and industrialization variables have multiplied to the GDP (constant 2010 US$) and divided to the population before being expressed in their natural logarithms and for the urbanization, we have used the linear interpolation method to decide the number of the urban population (individuals).

3.3. Econometric methodology

The empirical methodology applied in this research paper takes place in three stages while starting with the determination of the degree of integration of the concerned variables. In econometric literature, several statistical tests are used to verify the degree of integration [41]. propose the tests that will be used in this paper for Augmented Dickey-Fuller (ADF) test and [42] for Phillips-Perron (PP) test. Once the order of integration of the series is known, the next step will be to examine the possible presence of cointegrating relationships that may exist in the long-run among the variables. In this context, we will use the ARDL cointegration technique presented by Ref. [43] and has been developed by Ref. [44]. This technique has several advantages compared to other methods of cointegration: (i) it does not require the assumption that all the variables must be integrated in the same order. In other words, this technique can be used even if the variables are I(0) or I (1). (ii) it is not sensitive to the sample size, so it is considered more suitable when the number of observations is limited. The ARDL model used in our analysis is expressed as follows:

$$\begin{aligned}\Delta lnEG_t = \alpha_0 &+ \sum_{k=1}^{n}\alpha_{1k}\Delta lnEG_{(t-k)} + \sum_{k=1}^{n}\alpha_{2k}\Delta lnEC_{(t-k)} + \sum_{k=1}^{n}\alpha_{3k}\Delta lnED_{(t-k)} \\ &+ \sum_{k=1}^{n}\alpha_{4k}\Delta lnTL_{(t-k)} + \sum_{k=1}^{n}\alpha_{5k}\Delta lnInd_{(t-k)} \\ &+ \sum_{k=1}^{n}\alpha_{6k}\Delta lnUrb_{(t-k)} + \beta_1 lnEG_{(t-1)} + \beta_2 lnEC_{(t-1)} + \beta_3 lnED_{(t-1)} \\ &+ \beta_4 lnTL_{(t-1)} + \beta_5 lnInd_{(t-1)} + \beta_6 lnUrb_{(t-1)} + \varepsilon_t \end{aligned} \quad (4)$$

where, ε_1 describes the white-noise error term. Δ represents the first-difference operator. The null hypothesis (H_0) of no cointegration for equation (4) states that $(H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6)$ compared to the alternative hypothesis $(H_1 : \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6)$. Further [44], have fixed for each level of significance two classes of critical values relating to the lower and upper limits, corresponding to the situation where the order of integration of the series is I(0) and I(1), respectively. When the calculated statistical value is superior to the upper limit, the H_0 hypothesis is rejected, and therefore the existence of a long-run cointegration relationship is confirmed. Nevertheless, when the calculated statistical value is inferior to the lower bound of the ARDL test, the H_0 hypothesis is confirmed, hence the absence of a long-run cointegration relationship. Besides, when the calculated statistical value is between the two limits of the test, in this case, the cointegration test is judged inconclusive and we cannot interpret it.

We now turn to the presentation of the third stage that concerns the determination of the short- and long-run Granger causality test among the variables. In this study, we will propose VECM technology to find the direction of causality between EC, ED, TL, industrialization, urbanization, and EG. This technology is identified as the most proper method to decide and/or to measure causality. Thus, the VECM empirical equation proposed in our study is presented as follows:

$$\begin{bmatrix} lnEG_t \\ lnEC_t \\ lnED_t \\ lnTL_t \\ lnInd_t \\ lnUrb_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \sum_{k=1}^{n} \begin{bmatrix} \alpha_{11k}\alpha_{12k}\alpha_{13k}\alpha_{14k}\alpha_{15k}\alpha_{16k} \\ \alpha_{12k}\alpha_{22k}\alpha_{23k}\alpha_{24k}\alpha_{25k}\alpha_{26k} \\ \alpha_{13k}\alpha_{23k}\alpha_{33k}\alpha_{34k}\alpha_{35k}\alpha_{36k} \\ \alpha_{14k}\alpha_{24k}\alpha_{34k}\alpha_{44k}\alpha_{45k}\alpha_{46k} \\ \alpha_{15k}\alpha_{25k}\alpha_{35k}\alpha_{45k}\alpha_{55k}\alpha_{56k} \\ \alpha_{16k}\alpha_{26k}\alpha_{36k}\alpha_{46k}\alpha_{56k}\alpha_{66k} \end{bmatrix} * \begin{bmatrix} \Delta lnEG_{t-k} \\ \Delta lnEC_{t-k} \\ \Delta lnED_{t-k} \\ \Delta lnTL_{t-k} \\ \Delta lnInd_{t-k} \\ \Delta lnUtb_{t-k} \end{bmatrix} + \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ \gamma_5 \\ \gamma_6 \end{bmatrix} * ECT_{t-1} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \\ \varepsilon_{6t} \end{bmatrix} \quad (5)$$

where ECT_{t-1} determines the error correction term is statistically significant with a negative sign then the long-run causality exists. Concerning the short-run causality, we propose the Wald test to the difference and lag difference coefficient of all explicative variables.

Table 2
Descriptive statistics and correlation matrix.

	EG	EC	ED	TL	Ind	Urb
Mean	26.632	24.921	19.337	30.960	30.631	16.338
Median	26.605	25.160	19.371	30.883	30.591	16.500
Max	27.279	26.388	20.288	31.593	31.278	17.176
Min	25.771	22.555	17.906	30.046	29.782	14.944
SD	0.378	1.067	0.632	0.400	0.420	0.637
Skewness	0.075	−0.823	−0.303	−0.048	−0.309	−0.650
Kurtosis	2.340	2.773	2.245	2.159	2.223	2.325
Jarque-Bera	0.933	5.636	1.916	1.460	2.013	4.388
Probability	0.626	0.059	0.383	0.481	0.365	0.111
EG	1					
EC	0.816	1				
ED	0.901	0.963	1			
TL	0.914	0.618	0.749	1		
Ind	0.896	0.532	0.673	0.952	1	
Urb	0.833	0.987	0.969	0.627	0.555	1

Notes: Max, Min, and SD are maximum, minimum, and standard deviation, respectively.
Data spanning/country: 1971 to 2019/the KSA.

4. Empirical findings and discussion

4.1. Stationary tests

The implementation of the different stationarity tests for each series led to the results summarized in Table 3 below. As already mentioned before this research paper using the ADF and PP unit root test on the natural logarithms of the series in level and difference forms. The tests on the 1st difference series allow us to reject the null hypothesis (H_0) of no-stationarity for all variables at 1% thresholds, therefore, not stationary in level compared to the results of ADF and PP tests. Thus, all the variables of this study are stationary at the first difference.

4.2. ARDL cointegration tests

In this study, the ARDL cointegration techniques are applied to investigate the long-run relationship among EC, ED, TL, industrialization, urbanization, and EG. In this context, we primarily decide the number of lags in equation (4) based on the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC). Table 4 below indicates the optimal number of lags according to the two criteria mentioned above, which is found to be two. After finding the optimal number of lags, we now apply the ARDL bound test for equation (4) to detect the presence of a long-run relationship between variables that are the subject of our study. Once one or more long-run relationships are determined, we continue by estimating this cointegration relationship (see Table 7).

The results of the Cointegration tests from Ref. [44] are reported in Table 5. In this context, the results say that the hypothesis of no cointegration can be rejected at the threshold of at least 10% for all the variables. Thus, we can deduce the existence of a long-run association among EC, ED, TL, industrialization, urbanization, and EG. Over the period 1971–2019, these six variables evolved following a common trend.

Besides, to verify the robustness of F-statistics, we suggest the Johansen cointegration in this research paper reported in Table 6. This last reveals the number of long-term equilibrium relationships among integrated variables of the same order regardless of the normalization applied. The output of Johansen cointegration [45] has generated two statistics: trace statistics and Eigenvalues. The findings of these two statistics mentioned that there are at least four cointegration relationships that exist and the null hypothesis of no cointegration can be rejected.

To estimate the coefficients of the short- and long-run relationship, the method used is that [44] have created on the estimation of the ARDL. The empirical results reported in Table 7 reveal that EC, ED and industrialization have a positive impact on EG in the short- and long-run. In more detail, a 1% rise in EC will lead towards 2.804% (2.287) increase in EG in the short-run (long-run). The finding is in accordance with the earlier studies of [28,38,40] and [2,24] who found a positive and significant relationship between EC and EG. Likewise, EC contributes to ED in the KSA economy. More precisely, a 1% rise in CO_2 emissions per capita improves real GDP per capita by 2.287% (0.870%) in the short-run (long-run). EC is one of the major causes of ED, which is related to the level of GDP. This finding appeals to policymakers to propose a strategy that moderates EC through the requirement of economic motivations for energy-saving towards breaks the ED in the KSA. Furthermore, a 1% rise in industrialization stimulates EG by 5.533% (0.152%) in the short-run (long-run). Consequently, the industrial sector in the KSA plays a leading role in realizing EG Ref. [11]; Ahmed and Zhao, 2018). Besides, the coefficient of TL is positive and statistically significant especially in the long-run (insignificant in the short-run) of the growth model, which approves that trade enhances the level of EG. More precisely, a 1% rise in TL may accelerate real GDP per capita by 0.967%. These results support the findings of [26,39,46,47]; and [14] since it shows that trade promotes EG. In addition, the short-run elasticity estimates of urbanization regarding real GDP per capita are positive and significant. Specifically, a 1% rise in urbanization stimulates EG by 2.123%. Nevertheless, in the long-run this coefficient is insignificant showing that urbanization has no effect on EG in the KSA economy [30,32]. As required, the coefficient of lagged error term i.e., ECM [CointEq (−1)] is negative and statistically significant even at 1% and 5% levels. These empirical results reveal the presence of a long-run relationship among EC, ED, TL, industrialization, urbanization, and EG exists in the KSA.

In this research paper, we apply several diagnostic and stability tests to decide the appropriateness of the specification of the model. The issue of functional form, non-normality, serial correlation, and heteroscedasticity is investigated by diagnostic tests that are stated in the lower part of Table 7. The empirical results concerning diagnostic tests mention that the specifications adopted are satisfactory. Likewise, the Jarque-Bera tests do not make it possible to decline the hypothesis of normality of the errors, the tests carried out to detect the presence of Autoregressive Conditional Heteroscedasticity (ARCH), and Breusch-Pagan-Godfrey residues in the estimated equation do not highlight a heteroscedasticity problem at the 5% threshold. The LM-test tests performed to detect the presence of correlated residues do not show any

Table 3
Unit root tests analysis.

Variables	ADF test		PP test		Order of Integration
	Level	First difference	Level	First difference	
lnEG	−1.575 (0.487)	−4.286* (0.001)	−1.621 (0.463)	−5.681* (0.000)	I(1)
lnEC	−2.249 (0.192)	−2.974** (0.045)	−1.961 (0.302)	−5.082* (0.000)	I(1)
lnED	−1.909 (0.325)	−7.443* (0.000)	−2.067 (0.258)	−7.554* (0.000)	I(1)
lnTL	−1.764 (0.393)	−6.164* (0.000)	−2.286 (0.180)	−6.164* (0.000)	I(1)
lnInd	−1.622 (0.463)	−5.225* (0.000)	−1.777 (0.386)	−5.225* (0.000)	I(1)
lnUrb	−2.265 (0.187)	−2.739*** (0.075)	−1.236 (0.650)	−7.164* (0.000)	I(1)

Note: *, ** and *** indicate significance at 1%, 5% and 10% levels, respectively.

Table 4
Lag length selection criteria for cointegration.

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	101.019	NA	7.07e-10	−4.043	−3.807	−3.954
1	456.749	605.498	8.83e-16	−17.648	−15.995	−17.026
2	539.543	119.787*	1.30e-16*	−19.640*	−16.569*	−18.4847*

[i] Designates lag order selected by the criterion.
LR: Likelihood ratio criterion. **FPE:** Final Prediction Error. **HQ:** Hannan Quinn criteria.

Table 5
Cointegration tests from [44].

Estimated model	Bound testing to cointegration		
	Optimal lag length	F-Statistics	Cointegration
F_{EG}/[EG/EC, ED, TL, Ind, Urb]	1,0,1,0,1,0	4.857*	Yes
F_{EC}/[EC/EG, ED, TL, Ind, Urb]	1,1,0,0,1,2	8.219*	Yes
F_{ED}/[ED/EG, EC, TL, Ind, Urb]	1,1,1,0,0,1	6.470*	Yes
F_{TL}/[TL/EG, EC, ED, Ind, Urb]	1,1,0,0,1,2	7.771*	Yes
F_{Ind}/[Ind/EG, EC, ED, TL, Urb]	1,1,0,0,2,2	5.375*	Yes
F_{Urb}/[Urb/EG, EC, ED, TL, Ind]	1,0,2,0,2,1	5.576*	Yes

Significance level	**Lower bound I(0)**	**Upper bound I(1)**
10%	2.26	3.35
5%	2.62	3.79
1%	3.41	4.68

Note: *, ** and *** indicate significance at 1%, 5% and 10% levels, respectively.

Table 6
Johansen Cointegration test.

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	5% critical value	Prob.
None *	0.765	134.525	95.753	0.000*
At most 1	0.365	66.447	69.818	0.090***
At most 2	0.347	45.064	47.856	0.089***
At most 3	0.264	24.971	29.797	0.162
At most 4	0.131	10.532	15.494	0.242
At most 5*	0.079	3.891	3.841	0.048**

Note: *, ** and *** indicate significance at 1%, 5% and 10% levels, respectively.

Table 7
Estimated coefficients from the ARDL model.

Dependent variable: lnEG					
Short-run results			Long-run results		
Regressors	Coefficients	t-Values	Regressors	Coefficients	t-Values
lnEC	0.116*	2.804	lnEC	0.888*	1.159
lnED	0.145**	2.278	lnED	0.489*	0.870
lnTL	0.090	1.418	lnTL	0.691**	0.967
lnInd	0.329*	5.533	lnInd	0.094*	0.152
lnUrb	0.157**	2.123	lnUrb	1.201	1.192
CointEq(-1)	−0.130*	−1.436	Constant	1.300	0.237
Diagnostic test statistics					
LM Test:	1.759				
Jarque-Bera test	3.891				
F-statistics	485.412*				
ARCH test	2.530				
Heteroscedasticity test	2.438				
R-squared	0.990				
Stability Analysis					
CUSUM	Stable				
CUSUMSQ	Stable				

Note: *, ** and *** indicate significance at 1%, 5% and 10% levels, respectively.

problem of autocorrelation of errors at the 5% level. Furthermore, the value of R-square for the model chooses goodness of fit. In the same context, to confirm the robustness of our findings we use structural stability tests constructed on the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests as proposed by Ref. [48]. The empirical results of these two tests are stated in the lower part of Table 7 and a graphical illustration is presented in Figs. A.1 and A.2. We notice that both the plots show that all the straight lines (drawn at the 5% level) are crossed by CUSUM and CUSUMSQ i.e., the plots of both CUSUM and CUSUMSQ are inside the boundaries (presented by the dotted red lines). Hence, the model of this study is stable, and estimated results are trusted and well respected for policy procedures.

4.3. The VECM Granger causality tests

The presence of cointegration among variables proves that there should be at least four causal relationships; however, it does not give its direction. Likewise, the current research investigates the direct causal relationship among the series by using ECM founded Granger causality tests. Such information is useful in making suitable environmental, energy, and economic policies for sustainable development for the KSA economic (Fig. 1). The results on the direction of the short- and long-run Granger causality are stated in Table 8. Concerning the long-run causality, all the ECT coefficients are negative and statistically significant implying the presence of feedback effect between variables. In this context, the KSA economy direction must consider the leading role of TL, urbanization, and industrialization in supervising the levels of EG and ED. Furthermore, it is necessary to mention that the KSA should prove a suitable energy policy that can contribute to enhancing the quality of the environment without breaking the level of EG Refs. [25,49].

In the short-run, the findings reveal that the EC, TL, and urbanization, Granger cause the EG, while EG, ED, industrialization, and urbanization Granger cause EC. Furthermore, we have found that EC, industrialization, and urbanization Granger causes the ED. Likewise, EG, EC, industrialization, and urbanization cause TL, while EC, ED, TL, and urbanization Granger cause industrialization. Besides, EC and ED Granger cause urbanization. In addition, eight bidirectional causal relationships are found between EG and EC; EG and TL; ED and EC; urbanization and EC; EC and industrialization; ED and industrialization; TL and industrialization; ED and urbanization. This result aligns with the growth assumption, which predicts that increased EC will lead to improved economic conditions. Otherwise, EC causes EG without a doubt the KSA economy is importantly supported by the energy sector.

So, the policies adopted in the energy field must take into consideration the importance of the energy sector and prioritize it throughout its various phases and especially about its ability as well as the quality of the services made, given that it acts directly on the EG of the governorate and can contribute to the sustainable development of the KSA. The empirical findings have indicated a strong impact of urbanization on EC and ED. EC as related to the level of income constitutes the principal contributor in ED. The fast rise of the level of urbanization in the KSA stimulates EC due to the higher income of most households and this might be among the explanations why urbanization generates ED [13, 50]. Furthermore, the development of the industry sector has a powerful effect on EC, ED, and urbanization and so, we explain it as an industry expansion impact since industrialization stimulates rapid urbanization.

The findings of this research paper have crucial importance for policymakers to advance energy policy for the KSA that take part in the braking of ED although conserving EG. In this context, the policymakers should consider the improvement of efficiency and prudence in EC, especially in industry. Besides, the government of KSA must enhance and/or consolidate the share of renewable energies in the total energy mix. Likewise, this study suggests that the KSA should follow a pragmatic industrialization policy joined with modest decarburization and energy-efficiency processes to assure industrial, economic, and sustainable development. Furthermore, introducing an extra open trade policy will be a way for the KSA economy to enhance EG and to stimulate green technology transfer, which generates the improvement of the environment quality.

5. Conclusion and policy implications

The contribution of this study consists to examine the preponderant role played by urbanization, trade, and industrialization with the environment-energy-growth nexus. This paper attempts to fill this relationship and expand the recent literature especially since no study has explored this gap for the KSA economy with data spanning from 1971 to 2019. The stationary analysis by using ADF and PP unit root tests has revealed that the entire series concerned are stationary at the first difference. Thus, the cointegration test results have shown the presence of a long-run association among the variables concerned. ARDL technology has contributed to the analysis of this research work. The results have signaled that EC, ED, and industrialization have a positive and significant effect on EG in the short- and long-run. Therefore, EC constitutes the major contributor to the rise of CO_2 emissions that is completely linked to the level of real GDP per capita. Likewise, the coefficient of TL is positive and statistically significant in the short-run

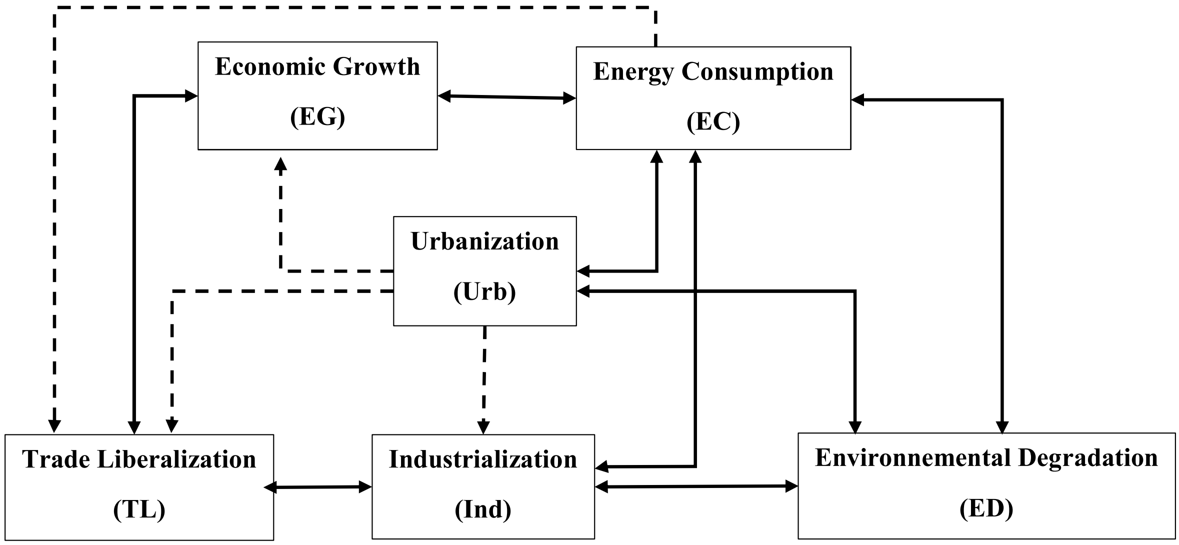

Fig. 1. Pairwise Granger causality results.

Table 8
Results of VECM Granger causality analysis.

Variables	Direction of causality						
	Short-run						Long-run
	ΔlnEG	ΔlnEC	ΔlnED	ΔlnTL	ΔlnInd	ΔlnUrb	ECT_{t-1}
ΔlnEG	–	4.605**	0.555	3.033***	0.997	7.314*	−0.091**
		(0.015)	(0.577)	(0.058)	(0.377)	(0.001)	(-2.452)
ΔlnEC	0.656*	–	1.044*	0.837	0.185*	3.632**	−0.009**
	(0.523)		(0.360)	(0.439)	(0.831)	(0.035)	(-0.216)
ΔlnED	0.325	2.228*	–	0.261	0.432*	0.739*	−0.061***
	(0.724)	(0.120)		(0.771)	(0.651)	(0.483)	(-1.001)
ΔlnTL	3.692**	3.378**	1.754	–	3.984**	8.082*	0.031***
	(0.033)	(0.043)	(0.185)		(0.026)	(0.001)	(0.423)
ΔlnInd	0.383	2.877*	0.463**	5.370*	–	9.389*	0.183***
	(0.683)	(0.067)	(0.632)	(0.008)		(0.000)	(2.802)
ΔlnUrb	1.565	2.505***	2.474***	1.049	2.116	–	−0.005*
	(0.221)	(0.093)	(0.096)	(0.359)	(0.133)		(-5.617)

Note: *, ** and *** indicate significance at 1%, 5% and 10% levels respectively.

(insignificant in the long-run), which approves that trade accelerates the level of EG in the case of the KSA economy. Concerning urbanization with respect to real GDP per capita, the elasticity estimate is positive and significant in the short-run. The Granger causality analysis has revealed that the entire ECT coefficients are negative and statistically significant proposing a feedback effect in the long-run among the different variables. In the short-run, the findings have revealed that for the KSA energy use, trade, and urbanization, Granger causes the EG, while growth, environment, industrialization, and urbanization Granger causes EC. Furthermore, we have found that energy, industrialization, and urbanization Granger causes the ED. In addition, eight bidirectional causal relationships have been found between the variables concerned. There is sufficient evidence to say that Saudi Arabia risks becoming a country specializing in polluting industries. However, given the results obtained, certain recommendations are called for: (i) Implement concerted actions with neighboring countries or with other partner countries before adopting an environmental regulatory policy. (ii) Subsidize and/or encourage economic agents who adopt economical technological innovations in terms of energy consumption and CO_2 emissions. (iii) Encourage and develop organic agriculture and reforestation programs to increase the capacity of trees or forests to deal with excess CO_2 emissions. (iv) Tax the big polluters to get them to adopt measures to reduce CO_2 emissions.

In total, our empirical findings take part in progressing the current literature and open new perspectives for decision-makers and urban planners in the KSA to formulate and/or to develop comprehensive economic, energy, and trade policies to support industrialization by enhancing the quality of the environment. Consequently, the political and institutional intervention of a careful government should even be much more important when the proportion of pollution linked to consumption starts to increase. In addition, the inseparability of pollution and consumption would cripple many individuals in their environmental protection goals. Given the high rate of private vehicle ownership by Saudi households, it is, therefore, to be feared that the strong EG of the KSA will lead to a particularly important augmentation in pollution linked to the use of these private vehicles during the next few years. In this case, for effective pollution control, government intervention will be essential. The existence of an efficient economic and energetic system is also a prerequisite for active and effective international cooperation in reducing CO_2 emissions. From another angle, the KSA government should push to consume less fossil and electric energies especially in the industrial sector, and develop sustainable energies with minimal impact of CO_2 emissions, such as solar given that the country has an abundant and available potential for solar energy but extraordinarily little exploited. Furthermore, develop infrastructure capable of consuming less energy (solar-powered trams, for example) and put a priority on the quality of imported automobiles. It is also suggested to decision-makers to make renewable energy available to all populations to encourage them to contribute more to the national GDP. Considering the results obtained, certain recommendations are in order: (i) implement concerted actions to adopt an environmental regulatory policy; (ii) subsidize and/or encourage economic agents who adopt economical technological innovations in terms of EC and CO_2 emissions; (iii) tax major polluters to get them to adopt measures to reduce CO_2 emissions. Finally, the achievement of economic progress and the preservation of the environment is a strategic goal for any economy; we believe that renewable energies, research and development, innovation, and information and communication technologies can be considered as key variables for other directions and perspectives of research and future study by integrating other more sophisticated econometric techniques.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research has been funded by Scientific Research Deanship at the University of Ha'il – Saudi Arabia through project number RG-21073.

Appendix

Appendix.1. A summary of variables

Variable	Meaning	Unit	Source
EG_t	Economic Growth	GDP per capita (constant 2010 US$)	WDI(2019)
EC_t	Energy Consumption	Kg of oil equivalent per capita	WDI(2019)
ED_t	Environmental Degradation	CO_2 emissions (metric tons per capita)	WDI(2019)
TL_t	Trade liberalization	(exports + imports)/GDP.	WDI(2019)
Ind_t	Industrialization	Share of industrial value added in GDP divided per capita.	WDI(2019)
Urb_t	Urbanization	Share of urban population in total population.	WDI(2019)

Appendix.2

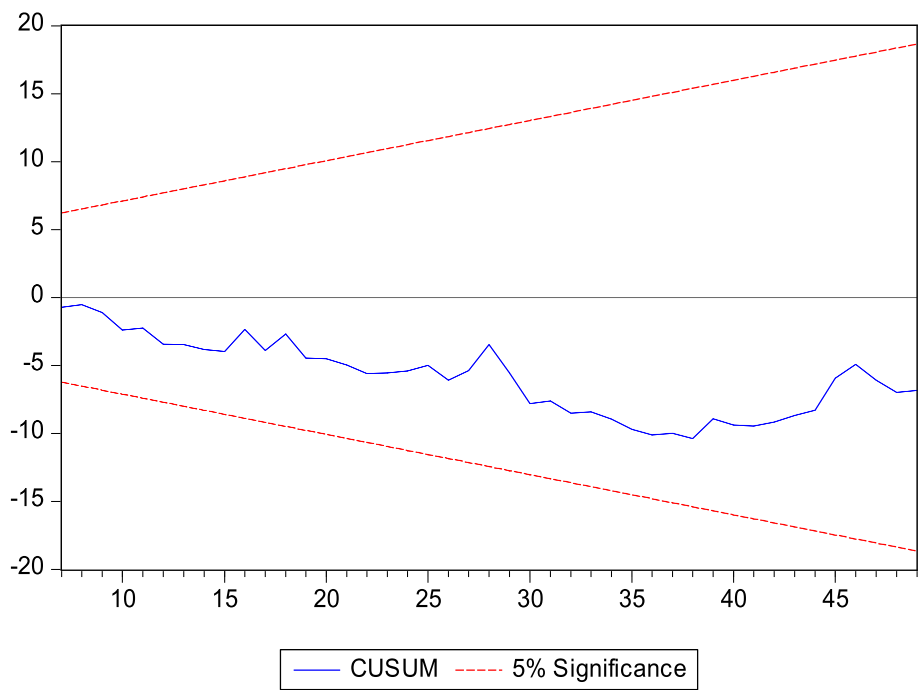

Fig. A.1. Plot of CUSUM.

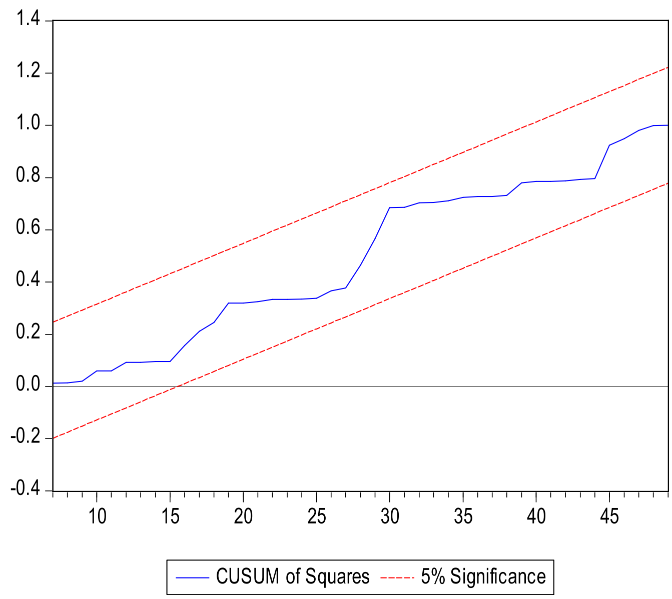

Fig. A.2. Plot of CUSUMsq.

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