Revisiting environmental Kuznets curve: An investigation of renewable and non-renewable energy consumption role

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Abstract

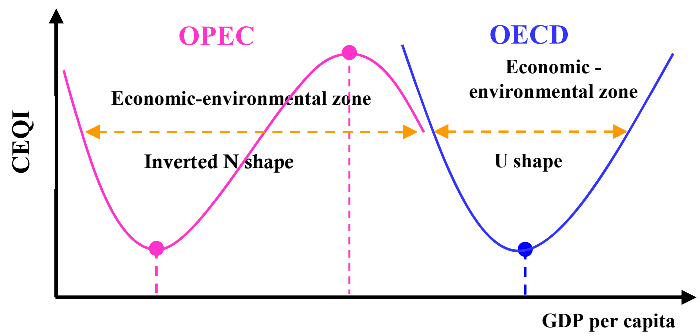
Empirical studies on the Environmental Kuznets Curve (EKC) hypothesis have not reached a consensus on their findings because different environmental indicators are used, among other reasons. So, this study proposes using a composite index encompassing all dimensions of environmental pollution, using the Composite Environmental Quality Index (CEQI). To do so, Continuously-Updated-Fully-Modified (CUP-FM) and Continuously-Updated-Bias-Corrected (CUP-BC) techniques are used for the panel of selected Organisation for Economic Co-operation and Development (OECD) countries and Organization in the Petroleum Exporting Countries (OPEC) from 2000 to 2019. The findings show that the EKC hypothesis is confirmed in the inverted N-patterned relationship for the OPEC countries and an inverted U- patterned relationship for the OECD countries. Our findings also declare that consumption of renewable energies (REC) significantly increases environmental quality (EQ) while consumption of non-renewable energies (NREC) adds to environmental degradation (ED). Further, the role of financial development (FD) in our composite index is respectively negative and positive for sampled OPEC and OECD economies. The positive coefficient of combined trade share (CTS) in both groups of studied countries indicates that this variable works to reduce ED. Lastly, the implications of these findings for economic-environmental policies are discussed.

Keywords: EKC hypothesis, Composite environmental quality index, Economic growth, Renewable and non-renewable energy

Highlights

- ❖ The EKC hypothesis is re-investigated using a new composite index for the environment.
- ❖ The inverted N-shape and U-shape are found for selected OPEC and OECD countries.
- ❖ REC and NREC have respectively positive and negative impacts on CEQI.
- ❖ CTS increases EQ both in selected sampled countries.

Graphical abstract



1. Introduction

Increased ED has accompanied the efforts of countries to achieve higher economic growth in recent decades. Hence, it has become one of the human societies' main issues and concerns. Accordingly, many researchers have scrutinised the influence of economic growth on EQ (Fakher 2019; Khan et al. 2021a; Shahzad et al. 2021). A well-known and widely used theoretical hypothesis for the correlation of per capita GDP and ED is the EKC, which assumes an inverted-U curve between the two indicators (Anwar et al. 2021; Wang and Zhang 2021; Dogan et al. al., 2020; Ehigiamusoe et al. 2020).

Many theoretical and empirical studies have addressed the EKC hypothesis, resulting in different and sometimes contradictory results discussing the significance of economic growth in increasing environmental pollution. In this regard, they are not the same (See, Fig. 1), and there are differences in the type of relationship between these two variables (Fakher et al. 2021a, b). This issue has cast doubt on the development and generalisation of the EKC hypothesis. According to the various environmental indices employed in these researches, the discrepancy in the results can be attributed to these studies' types of environmental indicators since the type of environmental indicators as a variable addressing different aspects of environmental pollution can play a critical and decisive role in the kind of relationship.

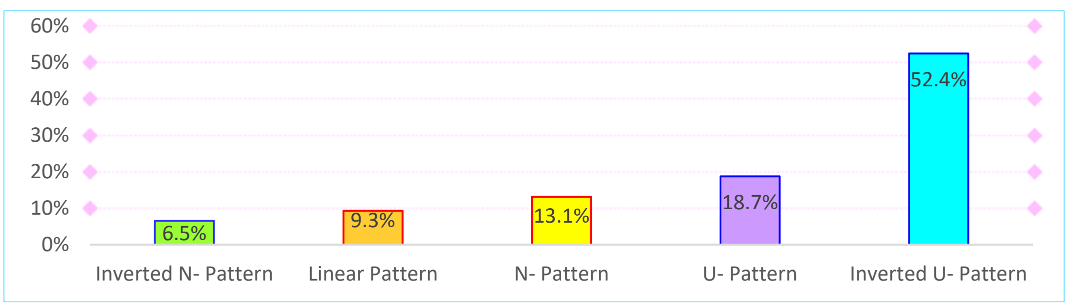


Fig. 1 Types of different relationships between economic growth and ED

Source: Authors' findings of the studies in Tables 1 and 2

In many studies, only one indicator is used to show the state of the environment. For instance, Murshed et al. (2021), Naqvi et al. (2021), Fakher et al. (2021a,b), Nathaniel (2020) and Fakher (2019) empirical works for ecological footprint index (EFI), Musa et al. (2021), Fu et al. (2020), Ozcan et al. (2019), Neagu et al. (2017) and Fakher et al. (2018) empirical models of their academic works for environmental performance index (EPI), Ganda (2019), Danish and Wang (2019) and Asici (2013) for adjusted net saving (ANS), Shah et al. (2019) and Long and Ji (2019) academic works for environmental sustainability index (ESI), Lee and Lin (2020) and Ho et al. (2019) empirical studies for environmental vulnerability index (EVI), Asici (2013) for pressure on nature index (PNI).

However, the critical question is whether only one indicator is enough to capture the complex nature of the status of the environment and its degradation and subsequently how the economic activities and development can influence it. The literature's lack of consensus might be attributed to this point of the differences in indicators.

On the other hand, due to the strong association between different levels of economic activities (economic development) and energy usage, energy is a necessary input for all financial functions, such as transportation of goods, electricity generation, trade, agriculture, and essential social services (education and health). Thus, energy contributes significantly to laying the foundation for the advancement and development of every economy (Ma et al., 2021; Sharif et al., 2020). Energy has been assumed to be the determining factor for economic growth and other production factors, and its significance has continuously increased. The energy sector has more interaction with different economic sectors due to its growing demand for rapid economic development and industrialisation (Khan et al. 2021a; Saud et al. 2019). Given that fossil fuels meet a large part of this demand, which has resulted in greenhouse gas emissions, economic growth seems to increase environmental pollution at first glance (Fakher et al. 2022).

Nevertheless, the reality is that economic growth does not necessarily cause environmental degradation. Empirical evidence shows that rapid economic development only causes a surge in pollution during the early stages of growth. Meanwhile, environmental issues have become more critical. The increasing trend of energy consumption and environmental pollution is reduced due to energy efficiency, environmental regulations, and increased public awareness at later stages of development (Usman et al., 2020; Shahzad et al., 2021).

Energy has the most significant contribution to changing environmental conditions than other factors (Ma et al., 2021). Regarding adverse ecological consequences of power, Myer and Kent (2001) believe that most greenhouse gas emissions, particularly carbon dioxide (CO2), are caused by fossil fuel combustion. Accordingly, there is a close relationship between the energy sector policies and environmental sustainability. The adverse impacts of energy on our environment require countries that rely on fossil energy to switch toward renewable energy because renewable energy is believed to be environmentally friendly (Ahmed et al. 2021a; Ahmed et al. 2021b).

More precisely, the study tries to scrutinise the role of economic growth on EQ, using a composite index for environmental quality within an EKC framework for selected OPEC and OECD countries, controlling for their differences in REC and NREC, FD and trade openness (TO). In doing so, CUP-FM and CUP-BC techniques are used for the panel from 2000 to 2019. The results of this study will help the countries' economic-environmental analysts and policymakers in formulating and implementing appropriate economic and environmental policies to obtain sustainable economic growth and development.

According to recent statistics on greenhouse gas emissions from 1990-to 2016, the average growth of carbon dioxide production in OPEC countries was higher than the global average (Elsalih et al. 2020). With numerous natural reserves such as oil reserves and fossil and mineral resources, the OPEC economies have turned to pollute industries not only by the indiscriminate consumption of natural resources but also by expanding their industrial sectors to obtain higher economic growth and development (Fakher 2019). Figure 2 shows the share of world crude oil producers in 2018. The OPEC countries account for about 43%, indicating that these countries have abundant oil resources and consume the fossil resources such as oil to achieve economic growth. Accordingly, ED is expected to increase in these countries and impose many environmental problems, as illustrated in Figure 3.

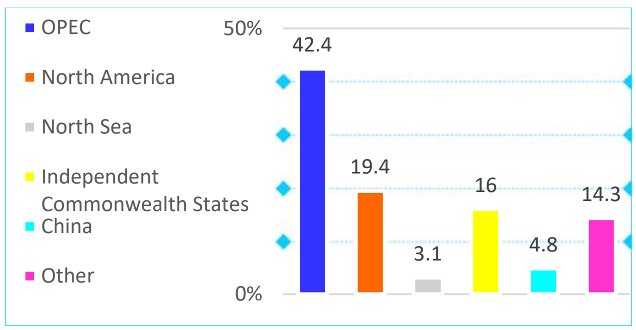


Fig. 2 Share of world crude oil producers in 2018

Source: BP Statistical Review (2020)

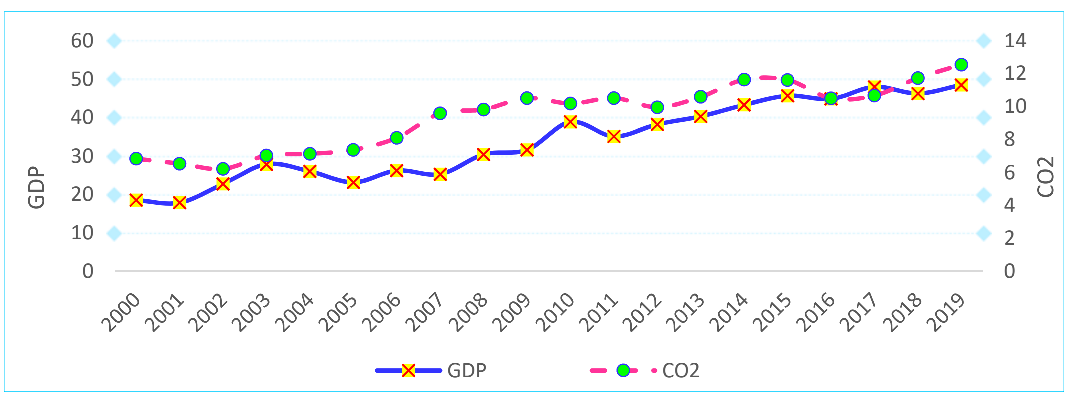
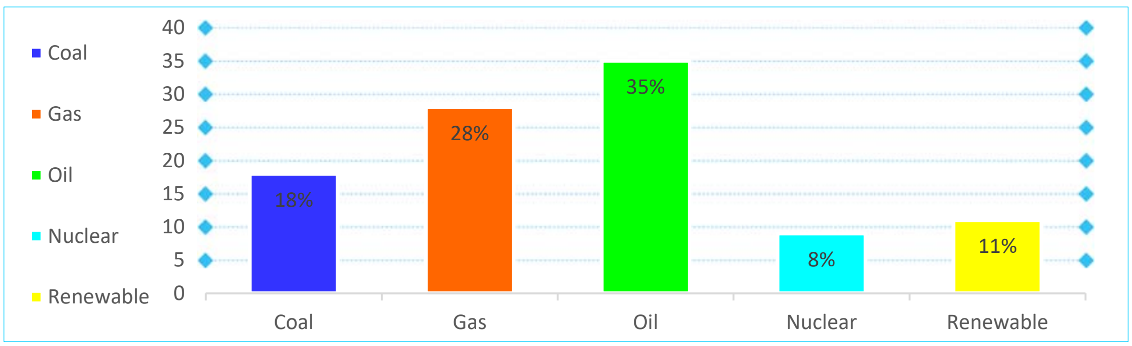


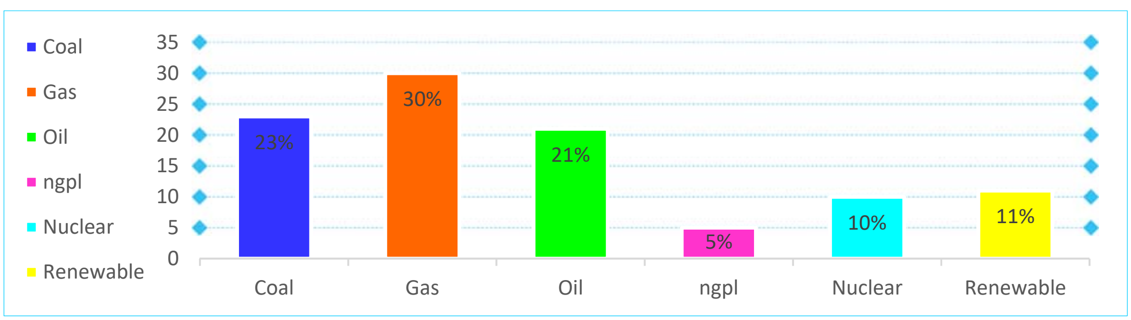
Fig. 3 Economic growth trend and ED

Source: BP Statistical Review (2020)

On the other hand, rapid industrialisation has escalated global energy demands (Acheampong et al., 2021). In this course, in accordance with the World Development Index (World Bank 2019), total world energy use is escalated by about 60%. 82% of the global total energy use comes from fossil fuels. The share of OECD countries was about 38% of total global energy use by 2018 (IEA 2020). Non-renewable sources (including oil, natural gas, and coal) cause this energy, about eighty-eight per cent for OECD countries; hence, exudations of CO_2 have enhanced significantly. During the last three decennaries, CO_2 emissions have escalated by about 63% globally, of which one third is attributed to OECD countries (IEA 2020). These exudations are the primary reason for critical environmental problems, such as global warming and climate change, threatening the whole planet. According to the World Bank (2019), the high amounts of GDP, including only 63% of global production, is for the OECD countries, indicating that most of the world's limited resources are used by the OECD countries. Statistics show that the most important part of the increase in energy demand for fossil fuels is associated with the OECD countries. Figure 4 shows the consumption and production of primary energy resources in these countries.



(A). Primary energy production in 2018



(B). Primary energy consumption in 2018

Fig. 4 Consumption and production of primary energy in OECD countries

Source: International Energy Agency (2020)

The trend of CEQI from OPEC and OECD economies' gross domestic product per capita (GDPPC) from 2000–to 2019 is depicted in Figure 5.

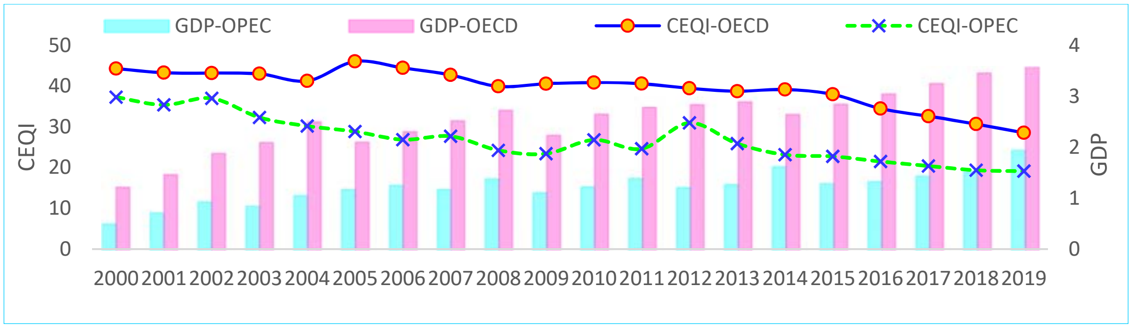


Fig. 5 The trend of CEQI from OPEC and OECD economies' gross domestic product per capita (GDPPC) from 2000–to 2019

Source: World Bank (2019) for GDP and authors' calculation for CEQI

Proposing a CEQI encapsulating all possible aspects of the concept might be the direction the literature needs to understand the relationship of the natural with the socioeconomic environment. To the best of our knowledge, this study is the first empirical study using a composite index (a combination of six environmental indicators) to examine the effect of economic growth on EQ within the EKC theoretical framework in sampled OPEC and OECD countries for the period 2000 - 2019. This study adopts such a composite environmental indicator as was firstly used by Fakher et al. (2021b) to examine the role of FD in the environment-economy nexus. Thus, the most significant contribution of the paper is the type of index that incorporates substantial aspects of the state of the environment (Fakher et al. 2021b). Furthermore, this study proposes several novel points in terms of content and method.

After, as discussed above, the main contribution of the composite indicator to demonstrate EQ; secondly, instead of using TO (the aggregated number of imports and exports normalised by GDP), the Combined Trade Share (CTS) is used in this study. This indicator (CTS) is used because TO alone cannot be a complete descriptor of the trade ratio. Thirdly, the current study's findings may offer additional perspectives on the critical function of the researched aspects in accomplishing the Sustainable Development Goals (SDGs). These variables were chosen regarding the OECD and OPEC economies because they are regarded as the most significant ecological degradation influencers and hence useful criteria for establishing environmental policy among those nations. Fourthly, methodologically, in addition to CUP-FM, CUP-BC was used to ensure the accuracy of the coefficient estimation. Since these approaches can provide reliable results considering autocorrelation, endogeneity, and cross-sectional dependence, they are preferred over other estimation techniques applied previously in the literature.

The present research is outlined as follows: For the section "Empirical literature review", an overview of previous empirical studies and different indices used in these researches is presented. The section "Data, model specification and research methodology" provides a succinct description of the studied data and explains the econometric methodology and the model specification. The section "Empirical findings and analysis" presents composite index construction and estimation results. Finally, in the section "Conclusion and implications", the most significant and prominent results are summarised, and policy recommendations are provided to policymakers. Additionally, the study's limitations and suggestions for future studies are presented in this section.

2. Empirical literature review

The first and the most well-known theoretical framework for the correlation of the economy with the environment in the environmental-economic literature, which describes a non-uniform relationship between economic growth and environmental pollution, is the EKC hypothesis. Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Grossman and Krueger (1995) conducted the first empirical studies in this field. According to this hypothesis, natural resources and energy use increases in the early stages of economic growth due to the high priority of production and employment over a clean environment, resulting in ED (scale effect). The composition of products changes from agricultural goods to industrial goods on the path of economic growth. However, the ED rate is reduced when economic growth reaches a threshold (composite effect). Due to the re-change of the product composition with a decrease in industrial production and an increase in services. Finally, technological advances (technical effect) in all production dimensions confirm this hypothesis. A summary pertaining to the interaction between per capita income and ED in the three economic stages is illustrated in Figure 6.

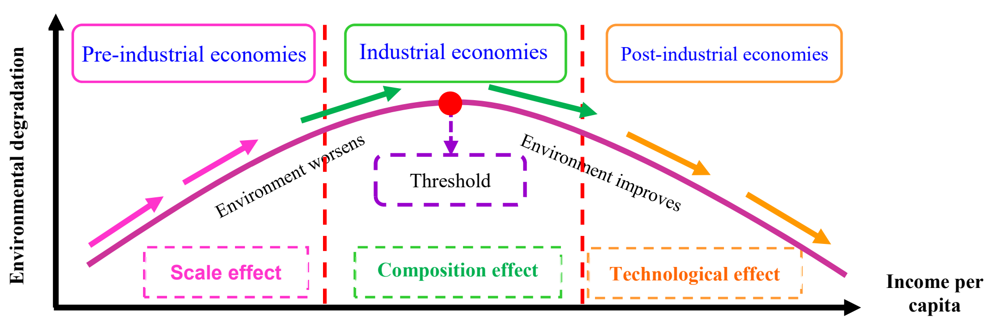


Fig. 6 Schematic representation of inversed U-shaped EKC hypothesis

Source: Bekhet and Othman (2018)

Due to the significance of this relationship, many studies have been conducted, with the main focus on the EKC hypothesis. The studies have led to different and sometimes contradictory results regarding the significance of economic growth in increasing environmental pollution (Fakher et al. 2021a, b). The different results can be caused by applying different econometric methods, the period under study, and the type of environmental indices. Because of the significance of important economic correlation with environmental factors and the expansion of empirical contexts on the influence of these factors on each other, numerous indicators in the environmental field have been delineated and used for empirical models of studies. Table 1 summarises the selected environmental indices employed in these empirical researches.

Table 1 The succinct diverse environmental indicators employed in empirical studies

Researcher/s	Time	Indicator	Researcher/s	Time	Indicator
Fakher et al (2021a)	2010–2019	EFI	Neagu et al. (2017)	2000-2016	EPI
Fakher et al (2021b)	2010–2019	EFI	Ganda (2019)	2001-2012	ANS
Murshed et al. (2021)	1995-2015	EFI	Salahuddin and Gow (2019)	1980-2016	ANS
Sultana et al. (2021)	1972-2018	EFI	Danish and Wang (2019)	1992-2013	ANS
Naqvi et al. (2021)	1990–2017	EFI	Asici (2013)	1970-2008	ANS
Ekeocha (2021)	1996-2014	EFI	Peter (2010)	2001-2006	ANS
Nathaniel (2020)	1971-2014	EFI	Gnègnè (2009)	1971-2000	ANS
Nathaniel et al. (2020)	1990-2016	EFI	Shah et al. (2019)	2006-2017	ESI
Usman et al. (2020)	1985-2014	EFI	Long and Ji (2019)	1996-2015	ESI
Dogan et al. (2020)	1980-2014	EFI	Charnkit and Kumar (2014)	1992–2005	ESI
Ahmed et al. (2019)	1971-2014	EFI	Olafsson et al. (2014)	2005-2017	ESI
Fakher (2019)	1990-2016	EFI	Lee and Lin (2020)	2000-2014	EVI
Elsalih et al. (2020)	2002-2014	EPI	Ho et al. (2019)	2007-2014	EVI
Fu et al. (2020)	2002-2016	EPI	Olafsson et al. (2014)	2005-2017	EVI
Ozcan et al. (2019)	2000-2013	EPI	Chen et al. (2021)	2000-2015	PN
Fakher et al. (2018)	1996-2016	EPI	Asici (2013)	1970-2008	PN

Note: EFI denotes Ecological Footprint Index; EPI Environmental Performances Index; ANS Adjusted Net Savings; ESI Environmental Sustainabilities Index; EVI Environmental Vulnerabilities Index; PN Pressures on Nature

The usage percentage of various environmental indices in previous empirical research as an indicator of environmental status in economic templates is depicted in Figure 7. This difference in the indicators can be one of the main reasons leading to different and sometimes contradictory results in previous studies.

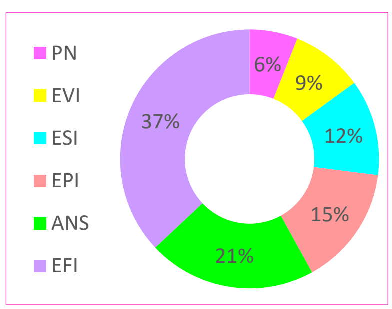


Fig. 7 The amount per cent of diverse environmental indices

Source: Authors' findings based on the studies in Table 1

With respect to the significant and remarkable role of impressive economic factors (namely economic growth, FD, NREC, and TO) in EQ, many studies have been carried out in the economic-environmental literature and achieved different results (a summary of selected recent studies in Table 2). This is one of the main issues and challenges in the environmental economics contexts attracting attention in recent times.

Table 2. A summary of major empirical examinations

Researcher/s	Time	Finding/s	Researcher/s	Time	Finding/s
ED - Economic growth connection					
Hao et al. (2021)	1991-2017	EKC pattern	Koc and Bulus (2020)	1971-2017	N-shaped
Sultana et al. (2021)	1972-2018	EKC pattern	Shah et al. (2020)	1980-2017	U-patterned
Khan et al. (2021b)	1990-2018	Positive	Khan et al. (2020a)	1990-2018	Positive
Saud et al (2020)	1990-2014	Inverted N-patterned	Ozcan et al. (2019)	2000-2013	N-shaped
EQ – FD connection					
Acheampong et al. (2020)	1980-2015	Positive	Saud et al. (2020)	1990-2014	Negative
Nwani and Omoke (2020)	1971-2014	Positive	Acheampong (2019)	2000-2015	Negative
Godil et al. (2020)	1986-2018	Negative	Seetanah et al. (2019)	2000-2016	Unspecified
EQ – NREC connection					
Sharif et al. (2020)	1965-2017	Negative	Fakher (2019)	1990-2016	Negative
Destek and Sinha (2020)	1980-2014	Negative	Khan et al (2019)	1991-2015	Negative
EQ – REC connection					
Ma et al. (2021)	1995-2019	Positive	Khan et al. (2020b)	1990-2017	Positive
Khan et al. (2021c)	1987-2017	Positive	Khan et al. (2020c)	1990-2017	Positive
EQ – TO connection					
Destek and Sinha (2020)	1981-2014	Positive	Nathaniel (2020)	1971-2014	Negative
Sharif et al. (2020)	1965-2017	Positive	Fakher (2019)	1990-2016	Negative

Note: Environmental Degradation (ED), Environmental Quality (EQ), Financial Development (FD), Consumption of Non-Renewable Energy (NREC), Consumption of Renewable Energy (REC), Trade Openness (TO)

Fakher et al. (2021b) scrutinised the performance of FD in the impressionability of the CEQI from economic growth in two categories of sampled OPEC and OECD economies in the course of 2008-2019. For both groups of the sampled economies, the negative performances of NREC and economic growth in the CEQI were confirmed. While TO has had a significantly positive influence on the EQ, the effects of FD on the composite indicator for both classifications of sampled OPEC and OECD economies were negative and positive, respectively. In a similar study, Wang and Zhang (2021) confirmed the positive effect of TO and the negative effect of NREC on EQ. However, the positive effect of TO on EQ was not approved in Usman et al. (2020) studies, and its negative effect on the EQ was emphasised. Khan et al. (2021a) used the generalised technique of moments (GMM) method to examine the role of REC and NREC in ED in the United States of America. The CO2 index and ecological footprint as ED indicators were used. The findings showed that NREC had a positive performance in CO2 exudations and ecological footprint. In other words, NREC causes ED. Moreover, the results indicated a negative correlation between REC and ED. Shahzad et al. (2021) empirical work examined the relationship between economic growth, NREC, and EFI in the United States from 1965- to 2017. According to the research results, NREC also escalates ecological footprint. Moreover, the existence of the EKC pattern was confirmed. Dogan et al. (2020), Anwar et al. (2021), Danish et al. (2020) and Sharif et al. (2020) empirical researches achieved the same findings. However, there was a U-shaped relationship between economic growth and ED in Altıntaş and Kassouri (2020) and Destek and Sinha (2020), an inverse N-shaped relationship in Saud et al. (2020) study, an N-shaped relationship in Koc and Bulus (2020) study, and a positive relationship in El-Aasar and Hanafy (2018) study. Using the panel data approach, the influence of NREC and FD on EFI in selected OECD countries from 1980- to 2014 was examined, indicating that NREC and FD had positive performances in the ecological footprints (Destek and Sinha, 2020). In a similar study, Fakher et al. (2021a) addressed NREC and FD, Sharif et al. (2020) examined NREC, and Godil et al. (2020) examined FD. These researchers reached similar findings. However, Fakher (2019) and Nwani and Omoke (2020) confirmed the negative effect of FD on ED. In similar research by Seetanah et al. (2019), uncertain results were obtained regarding the role of FD in ED. Ehigiamusoe et al. (2020) scrutinised the correlations of NREC and economic growth with ED in the pattern of the EKC hypothesis in middle-income countries from 1990 to 2014. In their study, carbon dioxide emissions were used as an indicator for ED. The results rejected the EKC hypothesis. The findings also showed a positive relationship between NREC and ED.

The abovementioned discussion shows impressive economic factors' significant and remarkable role, including economic growth, FD, NREC, and TO in EQ. In this context, a vast amount of literature has been conducted and achieved different results. A brief of the most important research is presented in Table 2. Given the general panorama of past-to-present literature, it can be inferred that consensus has not been reached in environmental and economic literature. Therefore, the possible hypotheses can be stated as follows:

Economic growth – EQ nexus

Concerning the inconsistency in the findings of the empirical studies, the following hypotheses can be stated:

1. *Hypothesis 1 (H1)*: The correlation between economic growth and CEQI used in this research follows the "U-patterned EKC" or "Inverted U-shaped EKC" for the selected 13 OPEC countries and 15 OECD economies.

2. *Hypothesis 2 (H2)*: The correlation between economic growth and CEQI used in this study follows the "N- patterned EKC" or "Inverted N- patterned EKC" for the selected 13 OPEC countries and 15 OECD economies.
3. *Hypothesis 3 (H3)*: The correlation of economic growth with CEQI used in this study follows a Positive or Negative pattern for the selected 13 OPEC countries and 15 OECD economies.

EQ – FD nexus

In conformity with the abovementioned literature on the EQ – FD nexus, three hypotheses can be presented as follows:

4. *Hypothesis 4 (H4):* The escalating impact of FD on CEQI used in this study is confirmed for the selected 13 OPEC countries and 15 OECD economies.
5. *Hypothesis 5 (H5)*: The mitigating effect of FD on CEQI used in this study is verified for the selected 13 OPEC countries and 15 OECD economies.
6. *Hypothesis 6 (H6)*: The insignificant relationship is corroborated for the selected 13 OPEC countries and 15 OECD economies.

EQ – NREC nexus

Referring back to the abovementioned literature on the ED - NREC nexus, the following hypothesis can be proposed:

7. *Hypothesis 7 (H7)*: The negative effect of NREC on CEQI used in this study is authenticated for the selected 13 OPEC countries and 15 OECD economies.

EQ – TO nexus

Reverting to Table 2 on the EQ – TO nexus, we can propose three hypotheses as follows:

8. *Hypothesis 8 (H8)*: The escalating effect of TO on CEQI used in this study is confirmed for the selected 13 OPEC countries and 15 OECD economies.
9. *Hypothesis 9 (H9)*: The mitigating effect of TO on CEQI used in this study is verified for the selected 13 OPEC countries and 15 OECD economies.
10. *Hypothesis 10 (H10)*: The insignificant linkage between TO and CEQI used in this study corroborates the selected 13 OPEC countries and 15 OECD economies.

After all the above empirical literature, a clear conclusion has not been drawn on the relationship between EQ and economic variables, especially in EKC. Reasoning from these observations, considering a comprehensive composite index encompassing all dimensions of environmental pollution presents a gap in the particular sub-field. In the present research, the economic growth performance in

EQ was considered in the form of EKC assumption and the interaction between FD, NREC, and CTS with EQ using the CEQI.

3. Data, theoretical framework, econometric methodology

This section will briefly explain the studied variables, model specification, and econometric strategy. To better understand them, we divided this section into three sub-sections. Lastly, a graphical diagram of the methodology and conceptual model is presented at the end of this section.

3.1. Dataset description

Due to the data availability, a set of annual data obtained for 13 OPEC countries and 15 OECD economies from 2000 to 2019 was used in the present study. To scrutinise the EKC framework and compare the performance of REC, NREC, FD, and CTS in EQ, the experimental research model introduced in Fakher et al. (2021a, b) and Anwar et al. (2021) academic works are presented as follows:

$$\mathrm{CEQI_{it}} = \mathrm{f}\left(\mathrm{GDP_{it}}, \mathrm{GDP_{it}^{2}}, \mathrm{GDP_{it}^{3}}, \mathrm{REC_{it}}, \mathrm{NREC_{it}}, \mathrm{FD_{it}}, \mathrm{CTS_{it}}\right) \tag{1}$$

In Eq. 1, $GDP_{it}, GDP_{it}^{2},$ and $\mathrm{GDP_{it}^{3}}$ represent gross domestic product, square of gross domestic product, and cubic of gross domestic product, respectively, to evaluate the N-shaped EKC. It should be noted that this variable has been used as per capita GDP (dollar at a fixed price in 2010) in research models. $NREC_{it}$ and REC_{it} also represent non-renewable energy use and consumption of renewable energies, respectively. NREC has been considered in research models as per capita consumption of energies (kg equivalent of crude oil). REC is used as a percentage of total final energy consumption. $\mathrm{FD_{it}}$ shows the FD. This variable has been considered based on the private sector - domestic credit ratio (% of GDP) in research models. $\mathrm{CTS_{it}}$ demonstrates CTS. Given that TO alone cannot be a complete descriptor of the trade ratio, instead of using the usual TO (derived from the ratio of total exports and imports to GDP), CTS is used in the present study, as introduced by Squalli and Wilson (2011) and used in Fakher et al. (2021a) study. This index considers the share of a country's trade flow regarding the size of the economy and the significance of a country's trade volume to the world trade (Popova and Rasoulinezhad 2016) [1]. $\mathrm{CEQI_{it}}$ represents a composite environmental quality index calculated in the present research using six environmental indicators, namely ecological footprints index (EFI), adjusted net savings (ANS), pressures on nature index (PNI), environmental performances index (EPI), Environmental sustainability index (ESI) and environmental vulnerability index (EVI)[2]. Moreover, data on GDP, FD, and CTS were extracted from the World Development Indices (World Bank[3] 2019). The non-renewable and REC data were obtained from the International Energy Agency. Regarding the data on environmental indicators, the following sources have been used to collect data: World Bank (2019)

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[1] For a comprehensive discussion on this index, see Squalli and Wilson (2011).
[2] For a comprehensive discussion on these indices, see Fakher et al. (2021b).
[3] See https://data.worldbank.org

for ANS and PN; Yale Center for Environmental Law and Policy[1] (YCELP) and Columbia University Center for International Earth Science Information Network (CIESIN) for EPI and ESI; South Pacific Applied Geoscience Commission (SOPAC) and the United Nations Environment Programme (UNEP) for EVI; Global Ecological Footprint Network, and National Ecological Footprint Account (NFA 2019) for EFI.

3.2. Model specification

Now, given that the main aim of the research is to scrutinise the EKC hypothesis using the CEQI, Eq. 1 can be extended as Eq. 2:

$$LCEQI_{it} = \alpha_0 + \alpha_1 LGDP_{it} + \alpha_2 LGDP_{it}^2 + \alpha_3 LGDP_{it}^3 + \alpha_4 LNREC_{it} + \alpha_5 LREC_{it} + \alpha_6 LFD_{it} + \alpha_7 LCTS_{it} + \varepsilon_{it} \quad (2)$$

Where the notation of the variables is as in the previous section.

All modelled variables are transformed into their natural logarithm to obtain elasticities and efficient estimates. In Eq. 2, the effect of main economic variables (namely per capita GDP, NREC, REC, FD, and TO as independent variables) on the CEQI as a dependent variable (a combination of six environmental indicators). Thenceforth, the coefficients α_i relate to the long-term elasticities of the CEQI concerning GDP per capita ($LGDP_{it}$), squared GDP per capita ($LGDP_{it}^2$), cubic GDP per capita ($LGDP_{it}^3$), non-renewable energy consumption ($LNREC_{it}$), renewable energy consumption ($LREC_{it}$), financial development (LFD_{it}), and composite trade share ($LCTS_{it}$) respectively. i insinuates the number of selected panel samples (1, 2, …, n); t represents the time-span (2000, 2011, …., n); ε_{it} is the error term and α_0 is the slope intercept in the model. The coefficient's signs (+/−) related to GDP (squared and cubic GDP) describe the shape of the curve (for details, see Table 3).

Table 3. The possible scenarios for the shapes of the EKC curve (see the study of Shujah-ur-Rahman et al. (2019) for more details)

Coefficient's sign (+/−)	Shape of curve
$\beta_{1i} = \beta_{2i} = \beta_{3i} = 0$	No relationship
$\beta_{1i} < 0 \; and \; \beta_{2i} = \beta_{3i} = 0$	Monotonic decreasing
$\beta_{1i} > 0 \; and \; \beta_{2i} = \beta_{3i} = 0$	Monotonic increasing
$\beta_{1i} < 0, \beta_{2i} > 0 \; and \; \beta_{3i} = 0$	U-shaped
$\beta_{1i} > 0, \beta_{2i} < 0 \; and \; \beta_{3i} = 0$	Inverted U-shaped (EKC hypothesis)
$\beta_{1i} > 0, \beta_{2i} < 0 \; and \; \beta_{3i} > 0$	N-shaped
$\beta_{1i} < 0, \beta_{2i} > 0 \; and \; \beta_{3i} < 0$	Inverted N-shaped
$\beta_{1i} > 0, \beta_{2i} > 0 \; and \; \beta_{3i} < 0$	Cubic polynomial inverted-U shaped
$\beta_{1i} < 0, \beta_{2i} < 0 \; and \; \beta_{3i} > 0$	Cubic polynomial U-shaped

[1] See https://epi.envirocenter.yale.edu/

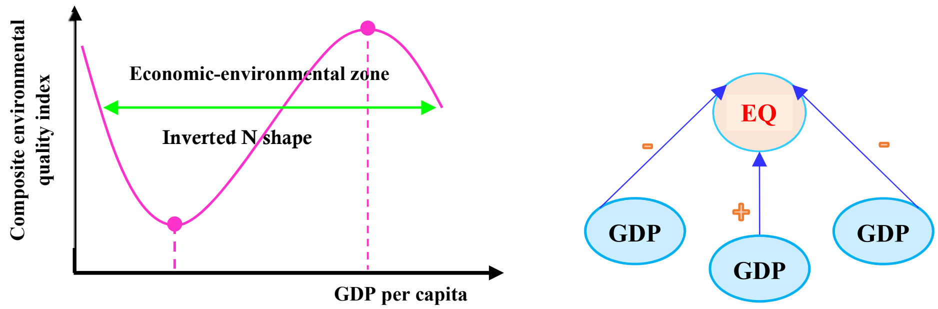


Fig. 8 Expected signs between GDP per capita and ecological footprint

A brief review of the research methodology associated with the model estimation is presented below.

3.3. Econometric methodology

According to the main objectives of this research, the selected model is a combination of equations (panel). One of the leading hypotheses in econometrics of composite data (panel) is the existence of cross-sectional dependence between the data used in the model. Accordingly, the first step is to evaluate (test) the presence of cross-sectional independence in the econometrics of data in the panel form. Several tests are employed to check the essence or absence of dependency of cross-sections. This research uses the Pesaran (2007) cross-sectional dependence (CD) test; one of the features is that it can be used for balanced and unbalanced panel data. Moreover, in addition to its favourable characteristics in small samples, due to one or more structural failures, it is resistant to slope coefficients of individual regression and provides reliable results. After checking the presence or absence of cross-sectional dependence, unit root tests should be performed to select the appropriate estimation method.

If cross-sectional dependence is confirmed, using the first-formation unit root tests as common panel unit root tests may lead to biased unit root results. To solve this problem, second-formation unit root tests named cross-section Im-Pesaran-Shin (CIPS) and cross-section-Augmented-Dickey-Fuller (CADF).

In the later stage, one should scrutinise the essence of long-term relationships between model elements. If cross-sectional dependence is confirmed, it is no longer possible to use the standard methods of first-generation panel cointegration tests. Using these methods in the presence of cross-sectional dependencies leads to false cointegration results. Accordingly, Westerlund's (2007) second-generation cointegration method can be used. Westerlund (2007) proposed four statistics of P_t, P_a, G_t, and G_a to examine panel cointegration. Panel statistics perform the hypothesis testing of the absence or the presence of cointegration $G_a$and G_t, and hypothesis testing of the absence or the presence of at least one cointegration vector is performed by the P_a and $P_t$panel statistics (Ulucak and Bilgili 2018). Bai and Kao (2006) and Bai et al. (2009) introduced a new estimator called Continuously Updated-Fully

Modified (CUP-FM), which was based on FM-LS. The panel data suggested that they have a cross-sectional dependence problem. To express this estimator, we consider the following panel model:

$$y_{it} = a_i + \beta x_{it}^{'} + e_{it} \qquad i = 1, \dots, n \;\; t = 1, \dots., T \tag{3}$$

Where, y_{it} is the dependent variable in the model. x_{it} represents the explanatory non-stationary variables, β is a $K \times 1$ dimensional vector of the slope parameters, and e_{it} shows the error term in the regression equation. According to Eq. 3, x_{it} can be expressed as explanatory variables in Eq. 4:

$$x_{it} = x_{i,t-1} + \varepsilon_{it} \tag{4}$$

Bai et al. (2009) presented the combined least squares estimator for the vector of β parameters in Eq. 5:

$$\hat{\beta}_{LS} = \left(\sum_{i=1}^{n}\sum_{t=1}^{T} x_{it}^{'} x_{it}\right)^{-1} \sum_{i=1}^{n}\sum_{t=1}^{T} x_{it} y_{it} \tag{5}$$

According to Philips and Hansen (1990), the limit distribution of this estimator is spaced from zero due to the skewness between e_{it} and ε_{it}. Accordingly, an FM-LS estimator can be presented for panel data using Philips and Hansen (1990) method to achieve long-term consistency and asymptotic normal distribution. To consider the cross-sectional dependence, Bai et al. (2009) assumed that the equation error and regression sentences follow the following pattern:

$$e_{it} = \acute{\lambda}_{it} F_t + u_{it} \tag{6}$$

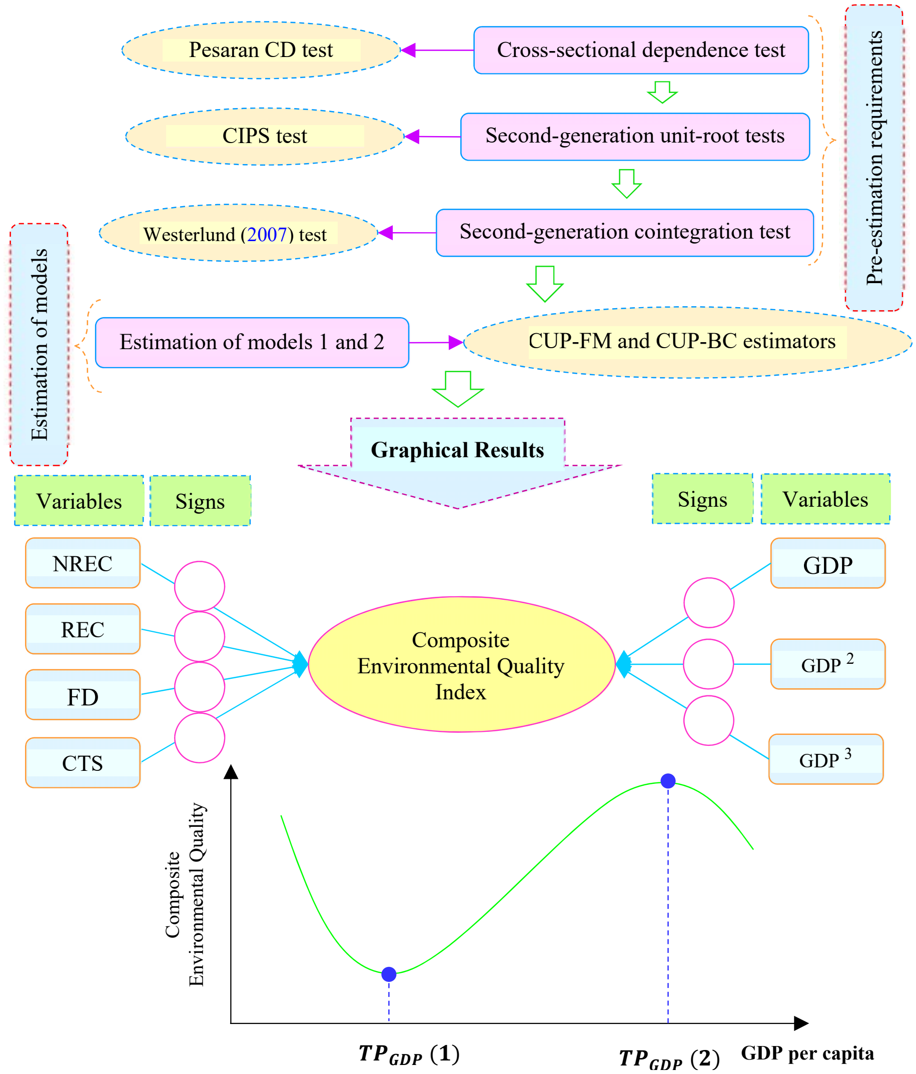
where, F_t is a r × 1 vector of invisible common factors, and λ_i is a r × 1 vector of factor loads; therefore, the panel model in Eq. 3 can be expressed as Eq. 7:

$$y_{it} = \acute{x}_{it}\beta + \acute{\lambda}_{it} F_t + u_{it} \tag{7}$$

If some of the components of x_{it} are stationary, and if a correlation is established between F_t and x_{it}, considering F_t as a component of the error term, the estimate would be inconsistent. Accordingly, separating F_t from the error term and inserting it into the regression function improves the estimates. Philips and Hansen (1990) proposed CUP-FM, which provides a consistent estimate of the coefficients of the equation in the form of Eq. 8:

$$\begin{aligned} \hat{\beta}_{CUP-FM} &= \left[\sum_{i=1}^{N} \acute{x}_i \, M_{\hat{F}} x_{it}\right]^{-1} \sum_{i=1}^{n} \left(\acute{x}_i M_{\hat{F}} y_i^{+} - T\left(\widehat{\hat{\Delta}}_{\varepsilon ui}^{+} - \acute{\delta}_i \widehat{\hat{\Delta}}_{\eta u}^{+}\right)\right) \\ \hat{F}V_{nt} &= \left[\frac{1}{nT^2} \sum_{i=1}^{n} \left(y_i - x_i \hat{\beta}_{CUP-FM}\right)\left(y_i - x_i \hat{\beta}_{CUP-FM}\right)^{'}\right] \end{aligned} \tag{8}$$

Accordingly, CUP-FM is obtained as a result of the iterative solution of $\hat{\beta}_{CUP-FM}$ and $\hat{F}$ in Eq. 8. According to what was mentioned, following Ulucak and Bilgili (2018) and Zafar et al. (2019) studies, in addition to CUP-FM, CUP-BC estimator was also used to ensure the accuracy of coefficient estimation. The results of these estimators are not affected by fractional integration and exogenous predictors (Ahmed and Le 2021c). Since these novel techniques are robust against residual autocorrelation, heteroscedasticity, cross-sectional dependency, and endogeneity (Ahmed et al. 2020; Ulucak et al. 2020), they are preferred over other estimation methods such as FMOLS and DOLS methods. Moreover, these estimation methods are reliable for small samples and provide consistent results. When the period of time (T) outpaces the cross-sections' numbers (N), these estimators (CUP-FM and CUP-BC) are more favourable as compared to other estimators. They may provide more reliable results (Nathaniel et al., 2021). In this study, T is greater than N; therefore, CUP-FM and CUP-BC estimators are suitable. The graphical diagram pertaining to the methodology and model of current research is depicted in Figure 9.



TP_{GDP} (1) and TP_{GDP} (2) : First and Second turnaround points for GDP related to CEQI

Fig. 9 A graphical diagram pertaining to the methodology and model of current research

Having a brief and helpful review of earlier empirical research, we came to the important point that one of the weaknesses and shortcomings observed in these studies is the lack of attention to the EKC with the presence of the CEQI. In this study, as shown in the conceptual model in Figure 9, the shortcomings and gaps in the literature have been eliminated to some extent; A conceptual model in which a CEQI is used as a dependent factor in the model.

4. Empirical findings and analysis

In this part, a CEQI is developed for the sampled OPEC and OECD economies. Next, the outcomes of the research model appraisal are presented and analysed.

4.1. Developing the composite environmental quality index

One of the most significant dimensions of our study regressor is environmental quality as the dependent variable. Grounded on six various attributes of environmental quality, we came up with a composite index for environmental quality. In this context, the empirical findings of Fakher et al. (2021b) studies on the composite index for environmental quality were used in this study. Their studies have introduced this composite using six environmental indicators and the artificial neural network (ANN) method. Following Fakher et al. (2021b), the same indices and the ANN method are used in this study to calculate the weight (efficacy) of each of the six environmental indicators for the selected sample. The weightings assigned to each index of the environment, such as performances (EPI), adjusted net saving (ANS), ecological footprints (EFI), environmental vulnerability (EVI), environmental sustainability (ESI) and pressures on nature (PN)— employed to develop CEQI. The weights of all EQ indices and the relevant mathematical equations are shown in Table 5 and Eqs. 9 and 10, respectively.

Table 5. Efficacy of each indictor used in this research

Indicators	OPEC economies	OECD economies
EFI	0.1882	0.2211
EPI	0.1681	0.1710
ESI	0.1258	0.1823
EVI	0.1012	0.0816
ANS	0.2118	0.1981
PN	0.2049	0.1459

Note: EFI denotes Ecological Footprint Index; EPI Environmental Performances Index; ANS Adjusted Net Savings; ESI Environmental Sustainabilities Index; EVI Environmental Vulnerabilities Index; PN Pressures on Nature

Source: Author's calculations

$$\mathrm{CEQI}_{OPEC} = 0.1882\mathrm{EFI} + 0.1681\ \mathrm{EPI} + 0.1258\ \mathrm{ESI} + 0.1012\ \mathrm{EVI} + 0.2118\ \mathrm{ANS} + 0.2049\ \mathrm{PN} \quad (9)$$

$$\mathrm{CEQI}_{OECD} = 0.2211\ \mathrm{EFI} + 0.1710\ \mathrm{EPI} + 0.1823\ \mathrm{ESI} + 0.0816\ \mathrm{EVI} + 0.1981\ \mathrm{ANS} + 0.1459\ \mathrm{PN} \quad (10)$$

In the present study, using the Eqs. 9 and 10, the CEQI is appraised for the sampled economies and applied in estimation regressions as a dependent variable (For further details on establishing a composite index for environmental quality, refer to Fakher et al. 2021b).

4.2. Estimation of3 the research model

As stated in the research methodology section, the first step in estimating panel data is to examine the test of the essence of cross-section dependency. The outcomes of this test are disclosed in Table 6. In accordance with the results of this test, the null hypothesis indicating that there is no cross-sectional dependence at the level of one per cent is rejected. Thereby, there is a cross-sectional correlation between the model factors.

Table 6. Results from Pesaran (2007) CD test

	Selected OPEC economies		**Selected OECD economies**	
Variables	**CD test**	**P-value**	**CD test**	**P-value**
LCEQI	12.400	0.000	18.826	0.000
LGDP	3.129	0.000	33.127	0.000
LNREC	2.465	0.001	25.185	0.000
LREC	2.816	0.000	42.930	0.000
LCTS	2.727	0.002	51.103	0.000
LFD	9.530	0.000	35.553	0.000

Then the unit root tests were conducted. Given that the dependency of cross-sections between the model elements is confirmed, we use the second- formation unit root tests (CIPS unit root test) to investigate the existence of a unit root. The test outcomes are documented in Table 7. According to these outcomes, all the model factors are at the non-stationary level and remain constant after one differentiating.

Table 7. Results from CIPS unit root tests

Variables	**Selected OPEC countries**		**Selected OECD countries**	
	CIPS		**CIPS**	
	Level	**First diff.**	**Level**	**First diff.**
LCEQI	- 2.062	- 3.115	- 1.537	- 3.924
LGDP	- 2.081	- 3.924	- 1.179	- 2.924
LNREC	- 1.389	- 3.517	- 2.039	- 3.024
LREC	- 1.729	- 3.347	- 2.337	- 3.505
LCTS	- 2.052	- 3.065	- 2.004	- 2.983
LFD	- 1.834	- 3.478	- 1.929	- 3.289

After examining the unit root test, the essence of long-term correlations among the model elements was discussed. Given the cross-sectional relationship among the model variables and the results obtained from the unit root test indicating that all model variables are integrated in the first order, the common panel cointegration tests may increase false and unrealistic results. Accordingly, Westerlund's

(2007) panel cointegration test was used, and the outcomes are documented in Table 8. Based on the group mean G_t and the panel statistic P_t The null hypothesis insinuating no coherence integration among the model elements is rejected. In other words, Westerlund (2007) cointegration test accepted the permanence of a long-run relationship among the model variables, and the research models can be estimated in the next step with no concern for false/biased regression. Before evaluating research models using CUP-FM and CUP-BC, it is necessary to run the F-Limer test to ensure the selection between the panel data method and the pooled data method. The null hypothesis of this test indicates the need to use pooled data, and its opposite hypothesis suggests the need to use panel data. According to the results of the F-Limer test, it is necessary to estimate the research models using the panel data method.

Table 8. Outcomes from Westerlund's (2007) test of panel cointegration

First model (Selected OPEC countries)			
Statistic	**Value**	**Z-value**	**P-value**
G_t	- 2.712	- 4.204	0.000
Ga	- 6.208	3.126	0.999
Pt	- 14.368	-3.718	0.000
Pa	- 5.520	3.442	0.674
First model (Selected OECD countries)			
G_t	- 2.612	- 4.102	0.000
Ga	- 5.508	3.413	1.000
Pt	- 13.218	- 2.859	0.003
Pa	- 5.329	0.572	0.999

With confidence in the panel data method and given the cross-sectional dependence between the model variables, CUP-FM and CUP-BC are used to estimate the long-term coefficients in the models. The results of these two tests for each of the research models are presented in Tables 9 and 10.

Table 9. Long-term assessment results for selected OPEC countries

Model: $\mathbf{CEQI = F(GDP, GDP^2, GDP^3, NEC, REC, FD, CTS)}$				
Variables	**CUP-FM**		**CUP-BC**	
	Coeff.	**T-stat.**	**Coeff.**	**T-stat.**
LGDP	- 0.512**	- 8.5674	- 0.416**	- 10.2341
LGDP ^{2}	0.096**	5.8291	0.044**	4.5801
LGDP ^{3}	- 0.013**	- 6.4921	- 0.011**	- 7.1036
LNREC	- 0.138***	- 3.3018	- 0.112***	- 4.7811
LREC	0.018***	3.7128	0.012**	5.0181
LFD	- 0.143***	- 4.4416	- 0.103***	- 8.5432
LCTS	0.015**	4.6239	0.008**	7.1205

Notes: *** and ** denote significance level at 1% and 5%, respectively.

The outcomes in Table 9 (in the case of selected OPEC economies) insinuate that, based on the correlations of per capita GDP with CEQI, the EKC assumption is rejected based on the results obtained from both CUP-FM and CUP-BC methods. In this regard, an inverse N-shaped correlation of per capita GDP with EC is confirmed. This finding is in line with those obtained in Saud et al. (2020) study. However, the results were in contrast with the EKC relationship in Anwar et al. (2021) study, an inverse N-shaped relationship in Saud et al. (2020) study, an N-shaped relationship in Koc and Bulus (2020) study, and a positive association in El-Aasar and Hanafy (2018) study. Moreover, a negative and significant relationship is noticed between the NREC and the CEQI. One per cent increment in NREC decreases the CEQI by 0.13% (CUP-FM) and 0.11% (CUP-BC), ceteris paribus. This relationship is as expected considering the literature and previous empirical studies. The OPEC countries are experiencing a high level of economic expansion at the cost of environmental deterioration. The reality has inspired this finding that these countries employ energy resources inefficiently and use the technologies with a high level of pollution. In other words, this group of countries with more revenues from oil sales could not consume these revenues properly to achieve their goals, the most significant of which is higher economic growth. Therefore, these countries should adopt energy efficiency policies to decrease pollution without affecting economic growth. In this regard, along with economic growth, they would most likely enjoy a clean environment. This finding is consistent with the results of previous studies (e.g., Fakher et al. 2021b; Wang and Zhang 2021; Sharif et al. 2020; Fakher 2019), highlighting the negative influence of NREC on EQ.

Furthermore, a positive and significant relationship between REC and the CEQI was confirmed as a one per cent increment in REC increases EQ by 0.018% (CUP-FM) and 0.012% (CUP-BC), ceteris paribus. This finding is in line with those reported by Khan et al. (2021a) and Altinas and Kasuri (2021). FD also has a negative and significant effect on the EQ as a one per cent increase in FD decreases EQ by 0.143% (CUP-FM) and 0.103% (CUP-BC), ceteris paribus. The results indicate that increasing domestic credit to the private sector in OECD countries increases environmental pollution. Concerning the inefficient and erroneous management of oil revenues, these revenues seem to be employed to expand consumption. Accordingly, the consumption pressures have led to more pollution and ED. In other words, FD did not lead to technological advancement in the industry; however, it increased the volume and size of industrial activities.

On the other hand, the negative environmental role of financial development can be due to the poor level of financial institutions. Godil et al. (2020) studies, as well as Acheampong's (2019) empirical research, confirm the present finding, whereas this outcome repudiates the positive relationship reported in Nwani and Omoke's (2020) empirical study and the uncertain relationship by Seetana et al. (2019). CTS's positive and significant role in the CEQI indicates that the increase in CTS to promote EQ is equal to 0.015% (CUP-FM) and 0.008% (CUP-BC). It can be inferred that countries' feedback from competing pressures resulting from the expansion of trade openness and having proportional advantage has resulted in the adequate consumption of resources and thus mitigated the level of energy and resource waste and pollution. This outcome is congruity with the results of Sharif et al. (2020) and Destek and Sinha's (2020) empirical works; however, it contradicts those reported by Nathaniel (2020) and Fakher (2019), indicating the negative relationship between TO and EQ (Figure 10).

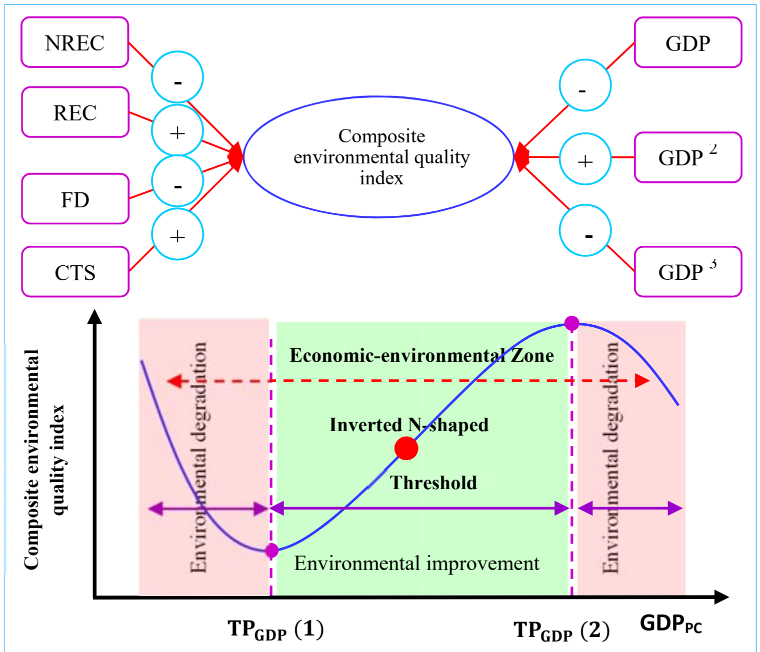


Fig. 10 A visual summary of the results from the model estimation for selected OPEC countries

Table 10. Long-term assessment results for selected OECD countries

Model: CEQI = F(GDP, GDP², GDP³, NEC, REC, FD, CTS)				
Variables	**CUP-FM**		**CUP-BC**	
	Coeff.	**T-stat.**	**Coeff.**	**T-stat.**
LGDP	- 0.821***	- 9.4051	- 0.612***	- 8.8553
LGDP ²	0.148***	11.5087	0.107***	10.8552
LGDP ³	- 0.058**	- 5.3076	- 0.011**	- 4.1068
LNREC	- 0.109**	- 6.8112	- 0.106**	- 10.1408
LREC	0.188**	2.8488	0.171**	3.5118
LFD	0.281***	4.5261	0.206***	4.3625
LCTS	0.118***	3.7714	0.098***	3.1175

Notes: *** and ** denote significance level at 1% and 5%, respectively.

As shown in Table 10 (in the case of selected OECD economies), considering the correlation between per capita GDP and the CEQI, the EKC assumption is confirmed based on the results obtained from both methods (CUP-FM and CUP-BC). Due to the high priority of production and employment over a clean environment, the consumption of natural reserves and energies increased in the initial stages of economic development, leading to ED. However, due to the environmental laws governing the production process, the appropriate environmental incentives in production processes, and the provision of services, manufacturers have shifted to the optimal use of natural resources and energy, thereby leading to a reduction in ED. This finding is in line with those reported by Shahzad et al. (2021) and Danish et al. (2020) and in contrast with the U-shaped relationship reported by Destek and Sinha (2020), the inverse U- shaped relationship documented by Anwar et al. (2021), and inverse N-shaped relationship stated by Saud et al. (2020). Since income in the OECD countries increases, these economies can devote more resources to investing in renewable, eco-friendly technologies and energy, leading to improvement of the quality of the environment. In the model related to the selected OECD countries, NREC has a negative role in the CEQI. As such, a one per cent increase in NREC significantly increases ED (a decrease in EQ) by 0.109% (CUP-FM) and 0.106% (CUP-BC). The inefficient consumption of energy resources as one of the motivations and instigators of economic growth seems to have led to an increase in ED in these countries. Fakher et al. (2021 a, b), Wang and Zhang (2021), and Sharif et al. (2020) confirm this finding. The REC coefficient is significantly positive, suggesting that a one per cent increment in REC decreases ED (an increase in EQ) by 0.188% (CUP-FM) and 0.171% (CUP-BC). This finding is in line with those reported by Khan et al. (2021a). The FD coefficient is significantly positive, suggesting that FD plays an efficient and effective role (0.281% (CUP-FM) and 0.206% (CUP-BC) of variations, ceteris paribus) in improving the EQ. This means that FD could absorb foreign direct investment and less pollution by providing the financial resources needed to access more effective and environmentally-safe technologies. This outcome is congruity with Fakher et al. (2021a, b) studies and Acheampong et al. (2020) and Fakher's (2019) academic works as well; However, this finding contradicts those reported by Wang and Zhang (2021) regarding the negative effect of FD on EQ and by Seetana et al. (2019) regarding the insignificant performance of FD in EQ. CTS also positively influences the CEQI, indicating that a one per cent increase in CTS increases EQ by 0.118% (CUP-FM) and 0.098% (CUP-BC), ceteris paribus. This means that technique and composition effects of trade openness dominate the scale effect, and the OECD countries specialise in the production of non-energy intensive goods and services.

Additionally, this finding can be attributed to the variation in production technology and the shift to clean and pro-environmental technology. In their study, Sharif et al. (2020) empirical research confirmed the positive correlation between CTS and EQ. This conclusion is congruity with the outcomes of this research. While Nathaniel's (2020) and Osman et al. (2020) empirical results indicating the presence of a significant negative performance of TO in EQ rejected the present research outcomes. A summary of the findings is also presented in Figure 11.

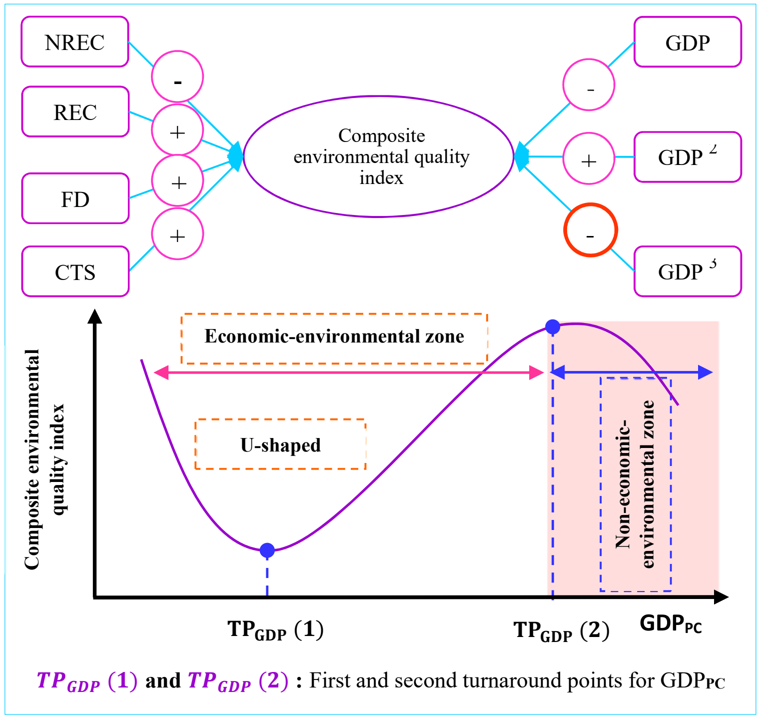


Fig. 11 A visual summary of the results from the model estimation for selected OECD countries

5. Policy implications of the findings for the two groups

According to the results of our analysis, some specific policy implications can be recommended for the two country groups. Particularly for the OPEC countries, given an inverse N relationship, these countries should consider establishing special ecological legislation and strategies to reduce ecological contamination and achieve a green and dynamic economy (SDG 8) and a clean and sustainable environment (SDG 13). Based on the mitigating effect of REC on ED, it is recommended to expand green development to move from conventional energy generation approaches to greener, more efficient generation strategies. Increased geothermal, nuclear, and wind energy generation should be allocated more attention. In this group of countries, the context and volume of green financing to stimulate renewable energy generation should be expanded to ensure that the masses have access to low-cost green energy (SDG 7).

As mentioned above, the analysis confirms an accelerating role of FD in environmental pollution. Owing to the inadequate quality of financial institutions, this negative consequence of FD can be attributed to the fact that a substantial level of institutional performance is required to improve economic advancement. As a result, effective and well-established financial organisations that can support green and eco-friendly enterprises and promote renewable energy developments will be helpful to ecological sustainability (SDG 7). This has resulted in current policies and regulations that are insufficient and restrictive in their efforts to foster technology, particularly in resource-rich economies. Governments should develop the required plans to improve environmental legislation and boost green technology development in these countries. By utilising green technology and supporting growth, measures must be devised to increase advantages while decreasing expenses. When regulations are not implemented effectively, they have a negative impact on the community and the economy by reducing their benefits and acting as a hindrance to economic progress and environmental protection. The limitation of technology, governmental intervention, financial resources, and investment in contamination control means these resource-rich nations (developing countries) are more vulnerable to contamination than developed economies. These countries are recommended to implement policies that prevent pollution while restricting economic development to achieve the SDGs.

Next, for the OECD group of countries, given the detrimental role of NREC in the quality of the environment, to boost energy effectiveness and contribute to environmental sustainability, which is one of the SDGs, OECD economies must support investment in research and development in general, and especially green technology development. Based on the study's empirical findings, the alleviating role of REC in environmental deterioration is verified. To mitigate ecological deterioration, government representatives and accountable institutions in OECD economies must implement efficient laws and policies to support financial expansion and innovative initiatives in clean energy sources. A clear linkage of FD with environmental quality is found regarding the obtained results. To enhance environmental quality in mind, OECD nations must support financial development by pursuing improvements that will help improve their financial institutions in line with the SDGs.

Moreover, the abovementioned findings disclosed the positive influence of CTS on the CEQI. This is why it is anticipated that the OECD countries not only concentrate on the manufacture of non-energy intensive products and activities but also that they are ascribed to variations in generation methodology as well as the transition to the employment of environmentally friendly and pro-environmental technologies in their manufacturing processes and operations (SDG 7). The strategies outlined above are essential for achieving the SDGs to advance socio-political, ecological, and economic purposes and synergies.

6. Conclusion and implications

In recent decades, the consumption of non-renewable natural resources and increasing economic growth have had many environmental consequences. The interaction between economic growth and ED has been one of human societies' main issues and concerns. In this regard, many studies examined the relationship between these two variables. However, due to different and sometimes inconsistent findings, the type of indicator or the number of selected indicators as a variable or variables expressing the state of the environment has always been considered one of the most remarkable and challenging issues. Accordingly, it is necessary to use a composite index encompassing all environmental pollution dimensions, which was disregarded in previous studies. In this respect, and unlike other research carried out in this area, the current study aimed to investigate the effect of REC, NREC, FD, CTS and per capita GDP on EQ in the form of the EKC hypothesis using a CEQI (introduced by Fakher et al. 2021b) during 2000-2019.

The findings obtained in this research are divided into two sections. The first section is for the sampled OPEC countries, and the second section is dedicated to the sampled OECD economies. The results of model appraisal for selected OPEC economies reveal that the correlation between per capita income and the CEQI follows an inverse N relationship. According to the results, the NREC has a significantly negative influence on the CEQI. In other words, due to the weakness of environmental laws governing the process of economic growth, less attention has been paid to the EQ and, accordingly, there has been a kind of inefficiency in the energy resource consumption and unwillingness to use clean technologies. The positive and significant effect of REC on the CEQI indicates that an increment in REC decreases ED. FD's negative and significant effect on the CEQI suggests that the increase in FD results in ED. In analysing this finding, it should be pointed out that oil revenues in the OPEC countries are used as surplus resources to improve the FD sector. However, due to a lack of proper management, these revenues could not play an efficient and effective role in strengthening and developing the financial sector to reduce pollution and ED. The positive sign of the CTS coefficient indicates that an increment of one unit in CTS leads to a decrease in ED and an increase in EQ.

The estimation results of the model for the selected OECD economies show that the correlation of per capita GDP with the CEQI follows a U-shaped EKC. NREC has a negative impact on the CEQI significantly. In this regard, the inefficient usage of energy resources as one of the drivers of economic improvements has led to an increase in ED. Moreover, the positive and significant effect of REC on the CEQI indicates that the rise in REC reduces ED. The FD coefficient is significantly positive, suggesting that an increase in FD decreases ED. This implies that FD has enabled employ more effective and environmentally-safe technologies in the area of energy use. Moreover, this further suggests that better environmental quality in OECD economies is linked with increasing the financial sector's depth, efficiency, and accessibility. CTS also has a positive influence on the CEQI significantly.

There are some common policy recommendations for two groups of OPEC and OECD economies to achieve SDGs through environmental quality improvement: These countries should minimise using non-renewable energy in manufacturing and other associated operations to enhance environmental quality through renewable energy employment. Enhancing creativity may be useful in converting non-renewable energy into renewable type. Energy efficiency can rise together with creativity in these countries, resulting in better environmental sustainability. Additionally, to reduce carbon emissions, it is recommended that these countries enhance their financial organisations and their role in renewable energy investments and innovation through fiscal expansion. By sponsoring eco-friendly initiatives, including renewable energy, the enhancement of financial expansion can help to minimise carbon emissions while simultaneously encouraging creativity through the financing of relevant initiatives. Other than this, these countries are urged to promote energy effectiveness, boost commerce and financial expansion by encouraging actions, compel filthy and energy-intensive enterprises to relocate to other countries with less stringent ecological restrictions, and fund academic hypotheses in their efforts to produce more energy effective equipment employed in manufacturing operations, and raise general knowledge about ecological preservation, to minimise the level of emissions. Finally, the traditional trade policies can be replaced by the green trade policies due to their contribution to improving environmental quality. For example, some tariffs can be imposed on the production process in which non-environmentally friendly energy is employed.

To facilitate understanding of the findings regarding the main objectives of this study, a schematic diagram of the findings is presented in Figure 12.

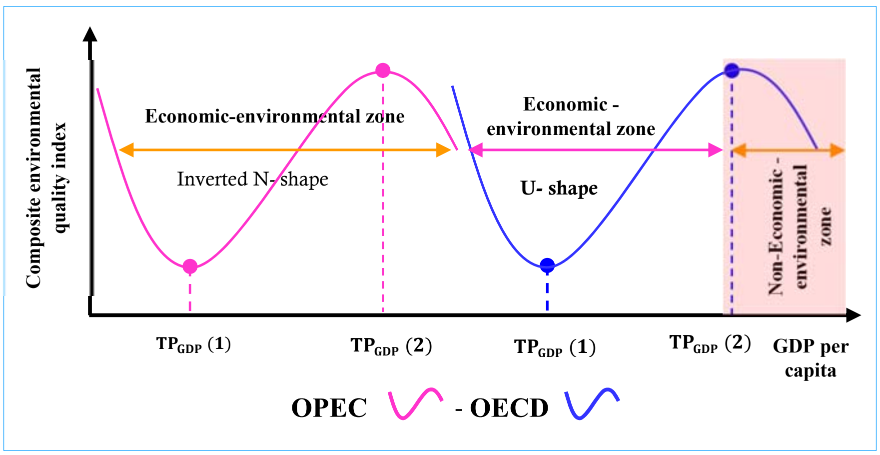


Fig. 12 Schematic diagram of significant results of this research

Apart from the obtained findings, the present study also had some limitations in providing future research opportunities. Due to data availability and the model focus and scope, the model does not claim to make any inferences on the type of renewable energies (only used as an aggregate). Accordingly, future studies are suggested to consider different types of renewable energies and main environmental indicators for three groups of developed, less developed and underdeveloped countries, in both time series and panel data setup. Future studies can also contribute to the existing environmental and economic literature by interpreting the model with alternate pollution indicators. Other than this, Future studies may also need to address the causal relationship between environmental indicators and economic growth in a system of simultaneous equations to control for interactions among them. Lastly, it is suggested to examine the EKC hypothesis considering the six environmental indicators used in this study, applying appropriate econometric techniques which can bring new perspectives for future studies.

Declarations

Ethical approval and consent to participate: NA

Consent for publication: NA

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