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The consumption of natural resources and its effects on environmental quality: Evidence from the OECD countries

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ABSTRACT

The existing body of literature has extensively investigated and debated the pivotal role of natural resources in the dynamics of economic growth. However, the explicit impact of natural resources on the quality of the environment is yet to be explored comprehensively. Amid this backdrop, this study explores the significant role that natural resources play in the growth processes of OECD member economies and the potential impact on environmental management. For our research model, the data for the OECD member countries (1997–2021) was collected from the "World Development Indicators (WDI)". We applied econometric tools namely, fixed effects, generalized least squares and two stages least squares for empirical results. A causality exercise based on the Dumitrescu and Hurlin (DH) is conducted to identify the direction causation. Our results show that the use of natural resources adversely impacts the quality of the environment in OECD economies. The square term of natural resources is negative and significant, confirming the validity of the environmental Kuznets curve (EKC) hypothesis between the use of natural resources and environmental degradation. When the cubic term of natural resources is entered into the estimated model positively, it shows that the potential shape of the EKC hypothesis is N-shaped. Our results also demonstrate that energy consumption and urbanization have worsened environmental quality, while trade openness and per capita income have improved the quality of the environment in OECD countries. The causality analysis showed several one-way as well as two-ways relationships. Our study's findings provide valuable insights from the OECD economies, which can be used to design and execute policies for managing natural resources to address environmental problems.

1. Introduction

Climate change is having an increasingly harsh impact on the world's finite natural resources. Growing levels of global deforestation, biodiversity loss, water scarcity, and life-threatening weather conditions such as random wildfire seasons are adversely affecting the regenerative capabilities of some of the renewable natural resources [1,2]. Nathaniel et al. [3] highlighted the potential threats linked with climate change, such as soil degradation, shortage of foods, the loss of biodiversity, and drought. Further, the endless destruction of natural resources will likely lower economic activity, reduce life expectancy, and accelerate poverty and urban congestion levels. Research [4,5] underscores that the over-exploitation of natural resources is bound to negatively influence the ecological balance and thereby threaten global environmental sustainability. Yet, the insatiable demand for consumer goods and policies aimed at achieving higher economic growth targets continue to diminish natural resources and the health of the environment [6,7]. Therefore, it is safe to posit that how a country consumes its natural resources would have serious environmental and economic consequences, negatively impacting the sustainability of its renewable resources.

Economic factors have received more attention in investigating environmental degradation because of their quantifying easiness. For

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instance, studies [8,9] indicate a significant positive connection between rising energy use, financial development, and environmental degradation. Sultana et al. [10] suggests that economic growth and increasing electricity usage owing to urbanization are the main factors behind ecological degradation in South Asian countries. Studies (e.g., [11,12]) posit that trade openness has unequal effects on carbon emissions across regions, thereby featuring its varied impact on environmental degradation. Fakher et al. [13] endorsed that growth negatively influences the quality of the environment. Natural resource-rich countries, usually characterized by rich fossil oil and natural gas resources, receive large economic revenues, and hence follow a passive policy towards renewable energy and environment quality [14]. On the other hand, Xu et al. [15] provided empirical evidence about the negative impact of cross-border tourism on CO2 emissions by employing a spatial hyperbolic model. Similarly, the findings of Liu et al. [16] based on the spatial hyperbolic model indicated an inverted U-shaped linkage between emissions from the industrial sector and growth. On the other hand, utilizing data from Chinese agriculture trade, Liu et al. [17] demonstrated that the spillover of technology does not cause a "pollution halo effect" in domestic areas; rather, this effect can be seen in adjacent areas. Finally, the recent paper of Liu et al. (2023) extended theory behind the EKC hypothesis and showed that watershed emissions from the agriculture sector indicate an inverted U-shaped relationship in the local markets and a U-shaped relationship in nearby areas. These findings are interesting and hence require further empirical investigations.

Prior studies [18,19] suggest that natural resource use has reduced the speed of environmental degradation. Current research [20] provided empirical evidence that the consumption of natural resources and environmental degradation are closely related and are one of the reasons behind environmental degradation in Bangladesh. On the other hand, Batool and Amjad [21] demonstrated that using natural resources has no tangible influence on the quality of the environment. Such opposing literature findings [22] underscore that the relationship between natural resource use and environmental degradation is still an open research question and demands further investigation, particularly in industrialized economies. Further, studies on the relationship between natural resources and environmental degradation are very limited, which is the prime motivation behind the current study.

Members of the "Organization of Economic Cooperation and Development (OECD)" are highly industrialized and own a vast and rich natural resource base. However, increasing energy consumption, urbanization, global economic integration, and natural resource usage have brought the environmental degradation challenges to prominence. Current literature [23] reported that OECD economies produce 35 % of global greenhouse gas emissions. Ahmad et al. [24] point out that a greater reliance on non-renewable energy sources is bound to increase CO_2 emissions in OECD economies. However, Zaidi et al. [25] pointed out that a positive relationship between natural resources and financial development in OECD countries. They showed that the presence of OECD countries' institutional quality plays an effective role in utilizing natural resources efficiently. Although OECD countries are continuously adopting macro sustainability measures to improve environmental quality [26], the current research remains vague regarding environmental quality in OECD countries. In general, the research literature is extensive about the determinants of environmental degradation. However, the explicit influence of natural resources on the quality of the environment is yet to be investigated comprehensively specifically in the context of OECD economies.

This study contributes to the environmental degradation literature in several ways. First, it measures the influence of natural resource use on environmental degradation in OECD economies, a relatively unexplored area in the concerned literature. Measuring the impact of natural resource use contributes a new dimension to the determinants of environmental degradation. It would assist OECD and developing economies policymakers in formulating strategies to mitigate environmental degradation under high natural resource usage. Second, this study explores the potential of the "N-shaped Environmental Kuznets Curve (EKC)", an unexplored phenomenon regarding natural resource use in OECD economies. Third, by using a suitable panel causality test, this study investigates the direction of causation. Lastly, it discusses the results and provides future avenues for OECD environmental protection policies.

The rest of the paper is as follows: Sections two and three provide a literature review and key statistics on the relevant variables. Section four describes the chosen data sample and the applied estimation model. Sections five and six outline the methodology, main results, and causality analysis results. The final section concludes the findings, suggests implications, and highlights and limitations.

2. Literature review

High levels of CO_2 emissions are responsible for deteriorating the environment. Recent research [27] also points out that there is growing global awareness of the impact of CO_2 emissions on the quality of the environment. Environmental degradation has received significant attention from policymakers and researchers over many years. Studies [28] identify energy use, trade, income levels, and urbanization as potential determinants of CO_2 and environmental degradation. Fakher [29] analyzed 22 determinants of ecological footprints by using two novel approaches namely, the "Bayesian Model Averaging" and Weighted Averaging Least Square". The mentioned study demonstrated that the negative coefficient of the square of income is ranked first, energy consumption is ranked second and population density is ranked third in terms of their impacts on environmental quality. Similarly, Fakher and Murshed [30] reported that economic growth initially improves the environmental quality index and later degrades the environmental quality after the threshold level. Nathaniel et al. [31] utilized recently adopted or state-of-the-arts techniques, including AMG, Driscoll-Kraay, and Prais-Winsten regression, and showed that international tourism is harmful to environmental quality. Can et al. [32] developed a green trade openness index and displayed that the inclusion of green products in the trade basket improves environmental quality. However, one key but relatively less researched determinant of environmental degradation could be the presence and extraction of natural resources in a particular country. Researchers have recently begun to focus on this topic due to the continually worsening quality of the environment. Islam et al. [20] report that natural resource use and environmental degradation are closely related. Isiksal et al. [33] provide evidence to support a positive relationship between the consumption of natural resources and environmental degradation. Sibanda et al. [34] drew similar conclusions by analyzing data from forty-two African economies. Akadiri et al. [35] also reported a one-way causal relationship running from natural resource use to environmental degradation by focusing on the economy of Nigeria.

Empirically, Huang et al. (2022) focused on the economy of the USA to study the linkages between financial development, natural resources, and environmental degradation by adopting the QARDL methodology using data from 1995 to 2015. Their results show that natural resource use has a positive and significant influence on the problems associated with environmental degradation. In other words, using natural resources harms the overall quality of the environment, even though they are important in fostering higher economic growth and development. Adebayo et al. [36] reported that the use of natural resources has the undesirable effect of reducing ecological quality in BRICS economies. Sicen et al. [37] also showed that natural resource rents are negatively associated with CO_2 emissions in the context of BRICS economies. In the context of the Chinese economy, Arslan et al. [19] documented that using natural resources improves environmental sustainability. These contradictory findings demonstrate the need for more comprehensive research studies.

Researchers have focused on establishing the determinants of environmental degradation in the OECD economies. For example, by analyzing data from OECD economies using a dynamic GMM estimator, Fakher and Ahmed [38] demonstrated that technological innovations are important for improving the quality of the environment. They have used six indicators of environmental quality and further showed that energy use and the development of the financial sector are primarily responsible for the worsening quality of the environment. Chen et al. [39] empirically showed that environmental taxes, strict environmental policies, and ecological innovation have improved the quality of the environment. Guloglu et al. [26] analyzed data (1980–2018) from 26 OECD economies and demonstrated that education, natural resources, and renewable energy improve the load capacity factor, while urbanization has increased environmental degradation. On the other hand, Neslihan [40] focused on 37 OECD economies to establish a link between democracy, renewable energy, and environmental degradation. The study empirically demonstrated that democracy negatively influences environmental quality as it increases CO_2 emissions. Fakher et al. [41] utilized composite indices of trade, financial development, and environmental quality and demonstrated that renewable energy and environmental quality enhance growth in advanced economies. Similarly, using data from developing economies for the period 1983–2013, Fakher and Abedi [42] showed that environmental performance is important for growth performance. Similarly, in the context of OPEC economies, Fakher et al. [43] showed that higher growth degrades the environment. Fakher et al. [44] proposed several indices for assessing environmental quality, such as "pressures on nature, ecological footprints, environmental vulnerability, and adjusted net saving". Their findings confirmed the N-shaped EKC. A recent study by Lee et al. [27] provided evidence to suggest that economic complexity increases both CO_2 and NO_2 emissions and the overall ecological footprint.

Our brief literature review shows that the impact of the use of natural resources on environmental degradation is inconclusive in the OECD economies and underscores the need to explore further the influence of the utilization of natural resources on the quality of the environment. This study also investigates this relationship in the framework of the EKC hypothesis to offer potentially new insights about the influence of natural resource usage on environmental degradation. By doing so, we try to identify whether the EKC hypothesis follows an inverted U-shape or N-shaped pattern. The literature is illustrated in Table 1. Some studies [34,36,45] support the positive influence of natural resources use on environmental degradation, while others suggest that natural resources have reduced the speed of environmental degradation [18,19]. Other researchers [21] concluded that the use of natural resources has no tangible influence on environmental quality. This study attempts to provide fresh empirical evidence about this relationship in the context of OECD economies.

The body of research literature extensively covers the determinants of environmental degradation. However, the explicit impact of natural resources on environmental quality remains largely unexplored in the current body of research. Particularly, in the context of OECD economies, research evidence is relatively scarce on the impact of natural resources on the quality of the environment. Therefore, this study is an attempt to explore and assess the potential impact of natural resources on the quality of the environment. Results will provide valuable insights to the OECD economies in formulating policy decisions and strategic initiatives, providing valuable insights and recommendations for fostering sustainable practices and mitigating environmental degradation.

3. Key statistics

Table 2 shows key statistics of OECD economies by averaging the data from the starting year (1997) to the end year (2021). For clarity, we present the percentage changes.

Table 2 shows that CO_2 emissions "(measured as metric tons per capita)" have declined by more than 17 percent during 1997–2021. This

Table 1
Summary of the Literature.

Author/s	Data Context and Time Period	Methodology	Findings
[45]	5 African economies; 1990–2019	Fixed Effects, Random Effects and FGLS	"Natural resources degrade the environmental quality".
[34]	42 African economies; 1994–2020	Generalized Method of Moments (GMM)	"Natural resources are positively related to environmental degradation".
[35]	The Nigerian economy; 1970–2020	"Breitung-Candelin Spectral Granger-causality and wavelet coherence analysis"	"Natural resources impact environmental degradation".
[46]	The Colombian economy; 1970–2017	Cointegration Analysis	"Natural resources degrade the environmental quality".
[36]	BRICS economies; 1990–2018	CS-ARDL, CCEMG	"Natural resources degrade environmental quality".
[37]	BRICS economies; 1995–2018	Panel cointegration techniques	"Natural resources enhance the environmental quality".
[22]	The USA economy; 1995–2015	QARDL	"Natural resources degrade the environmental quality".
[47]	22 African economies; 1980–2016	Panel cointegration techniques	"Natural resources degrade the environmental quality".
[23]	BRI economies for the period 1990–2018 African economies	Augmented Mean Group	"Natural resources degrade the quality of the environment".
[48]	The Ethiopian economy; 1971–2018	ARDL	"Natural resources deteriorate environmental sustainability".
[49]	The Uruguay economy; 1990–2020	ARDL	"Natural resources degrade the environmental quality".
[50]	BRICS members; 1990–2019	GLS and DH Causality Testing	"Natural resources degrade the environmental quality".
[51]	13 MENA economies; 1990–2016	DOLS, FMOLS	"Natural resources degrade the environmental quality".
[52]	GCC economies; 1993–2019	Cointegration Analysis	"Natural resources degrade the environmental quality".
[19]	The Chinese economy; 1970–2016	Cointegration and causality analysis	"Natural resources improve overall environmental sustainability".
[53]	BRICS members; 1991–2018	System GMM	"Natural resources degrade the environmental quality".
[18]	The Pakistan economy; 1990–2020	NARDL	"Natural resources enhance environmental quality".
[54]	N-11 economies; 1990–2016	Panel cointegration	"Natural resources reduce ecological footprint".
[21]	The Pakistan economy; 1980–2019	ANOVA and Correlation Analysis	"Natural resources have no tangible influence on

(continued on next page)

Table 1 (*continued*)

Author/s	Data Context and Time Period	Methodology	Findings
			environmental degradation".
[55]	The Nigerian economy; 1996–2018	SVAR Approach	"Long-term negative impact of natural resources on CO2 emissions".

Note: BRICS: "Brazil, Russia, India, China, South Africa" BRI: "Belt and Road Initiative", MENA: "Middle East and North Africa", GCC: "Gulf Cooperation Council", N-11: "Next Eleven Economies".

Table 2
Key statistics.

Variables	Description & measurement	1997	2021	Change (Percent)
CO_2	"Carbon emissions (metric tons per capita)"	8.620	7.131	−17.269%
NRSR	"Natural resources rents as a percent of GDP"	0.981	1.027	4.708%
PGDP	"Per capita GDP (Constant US $)"	26,236.690	37,886.950	44.404%
OPEN	"Trade openness (Trade as a percent of GDP)"	75.115	106.456	41.724%
ENGC	"Energy use (kg of oil equivalent per capita)"	3714.686	3565.090	−4.027%
URBN	"Urban population (% of total population)"	73.187	78.404	7.127%

Source: "Authors own calculation based on data from World Development Indicators".

decline shows the commitment of OECD economies to curb their emissions. Natural resources measured as "natural resources rents as a percentage of GDP" have slightly increased by 4.708 percent, a commendable achievement. The figures for 2021 show that the average contribution of resources to GDP is 1.02 percent for the member economies of the OECD. Per capita GDP "measured in constant US$" has increased enormously in the period studied by about 44.40 percent for the OECD economies. Further, the 2021 figures also show that per capita GDP is US$ 37,886 on average for the OECD economies, reflecting satisfactory economic performance over recent years. Higher per capita GDP has also contributed to the overall better quality of life in these economies.

The statistics in Table 2 also exhibit that trade openness has significantly increased by about 44 percent between 1997 and 2021. The OECD member economies are generally open to international trade as they impose few tariff and non-tariff restrictions. Trade as a percentage of GDP is a remarkable 106.456. Prior literature (Frankel and Romer, 1999; Sachs and Warner, 1995; Tahir and Azid, 2015) identifies trade openness as the engine of economic growth, one of the principal drivers behind the relatively higher economic growth in the OECD economies.

Our statistics show that energy consumption has fallen from 3714.686 "kg of oil equivalent per capita" in 1997 to 3565.090 in 2021, demonstrating a net decline of more than 4 percent. Urbanization usually places additional pressure on existing resources and degrades the environment's quality. Table 2 reveals that urbanization increased by more than 7 percent between 1997 and 2021. Therefore, the process of rural-to-urban migration should be monitored properly to reduce its adverse effects on the quality of the environment.

4. Modeling, data and methodology

4.1. Model building

Our baseline model to assess the consequences of natural resources use on environmental degradation in the OECD economies is as follows.

$$CO_{2it} = \gamma_0 + \gamma_1 NRSR_{it} + \eta_{it} \tag{1}$$

CO_2 emissions are taken as the dependent variable. "Natural resources rents as a percentage of GDP" is employed to capture the impact of natural resources use on environmental degradation. Earlier literature has repeatedly documented that environmental degradation is a complex process with several key determinants. The most prominent factors behind environmental degradation are international trade, income, urbanization, and energy consumption. Thus, we also included these determinants of environmental degradation in our model 2, given below.

$$CO_{2it} = \gamma_0 + \gamma_1 NRSR_{it} + \gamma_2 OPEN_{it} + \gamma_3 PGDP_{it} + \gamma_4 URBN_{it} + \gamma_5 ENGC_{it} + \eta_{it} \tag{2}$$

We are interested in seeing whether the traditional EKC validates the relationship between natural resource use and environmental degradation. For this validation purpose, we have included the square term of natural resources in our model 3 as follows.

$$CO_{2it} = \gamma_0 + \gamma_1 NRSR_{it} + \gamma_2 NRSR^2{}_{it} + \gamma_2 OPEN_{it} + \gamma_3 PGDP_{it} + \gamma_4 URBN_{it} + \gamma_5 ENGC_{it} + \eta_{it} \tag{3}$$

Model 3 includes the square term of natural resources as an additional variable for testing the EKC hypothesis concerning using natural resources and environmental degradation. For the validity of the EKC hypothesis, the coefficient of the linear term of natural resources must enter the estimated model positively, while the non-linear term should have a negative coefficient. In other words, in the estimated models, $\gamma_1 > 0$ and $\gamma_2 < 0$ if the EKC hypothesis is valid concerning the relationship between natural resources and environmental degradation. Finally, motivated by recent deliberations on the N-shaped EKC, we have also included the cubic term of natural resources in the model to explore whether the shape of the EKC hypothesis is an inverted U-shape or if it is N-shaped concerning the relationship between natural resources and environmental degradation. The traditional inverted U-shaped EKC has been questioned recently by many researchers. Therefore, we further investigated and moved from the existing literature to include the cubic term to see the possibility of an N-shaped EKC.

$$CO_{2it} = \gamma_0 + \gamma_1 NRSR_{it} + \gamma_2 NRSR^2{}_{it} + \gamma_3 NRSR^3{}_{it} + \gamma_2 OPEN_{it} + \gamma_3 PGDP_{it} + \gamma_4 URBN_{it} + \gamma_5 ENGC_{it} + \eta_{it} \tag{4}$$

In model 4, the cubic term of natural resources is included among the regressors. For the validity of the "N-shaped EKC hypothesis", between natural resources and environmental degradation, the linear term coefficient must be greater than zero, the square term must be less than zero, and the cubic term must be greater than zero ($\gamma_1 > 0,\ \gamma_2\langle 0,\ \gamma_3\rangle 0$).

4.2. Data sources and sample

Carbon emissions in "metric tons per capita" are used to measure CO_2 emissions. "Total natural resources rents as a percentage of GDP" are used for approximating the natural resource sector. Income level is captured by taking "real GDP per capita in constant US $" while "trade as a percentage of GDP" is used for quantifying trade. Finally, energy consumption is measured in "Kg of oil equivalent per capita," while urbanization is measured by considering "urban population as a percentage of the total population". Data for all selected variables in this study is taken from the "World Development Indicators (WDI)" period 1997–2021. This dataset is a free and reliable source extensively used by researchers in applied studies. We initially selected all 38 OECD economies but omitted Iceland due to data unavailability, resulting in a sample of 37 OECD economies.

4.3. Estimation techniques for analysis

For estimation purposes, this study adopts panel data techniques. Our study primarily focuses on the use of "fixed effects modeling (FEM)" and "random effects modeling (REM)", a widely used modeling approach in literature for assessing panel data. The FEM approach effectively cures the likely serial correlation problem between the regressors and the disturbance term. However, the FEM modeling cannot highlight the role of time-invariant characteristics due to the dummy variable trap problem (Tahir and Azid, 2015). On the other hand, the REM modeling approach can assess the role of time-invariant characteristics; it cannot work well when the chances of serial correlation are present between the regressors and the disturbance term. The choice between the FEM and REM approaches is resolvable by employing the Hausman (1978) specification test. The Hausman test result is displayed in Fig. 1.

Our study adopts the generalized least squares (hereafter written as GLS) method for estimation purposes. The GLS method verifies the robustness of results based on the conventional FEM approach. Researchers (e.g., Chen and Gupta, 2009; [8]) regularly employ this approach to check robustness. In addition, the study utilizes the "two-stage least squares (TSLS)" method to address the possible endogeneity problem.

5. Results and analysis

5.1. Preliminary testing

Before the main analysis, we conducted several important tests to confirm the use of the appropriate modeling technique and the absence of any serial econometric problem. The Hausman test confirmed the superiority of FEM modeling over REM modeling (see Table A1 in the appendix section). The results of the Peseran CD test also demonstrated the absence of cross-sectional dependence, which further justified the use of FEM modeling. Finally, the multicollinearity test (VIF) (see Table A3 in the appendix section) confirmed the desirable absence of multicollinearity in the estimated models.

5.2. Descriptive statistics

Table 3 reports the descriptive statistics. CO_2 emissions per capita are 8.119 t, with a standard deviation of 4.309. The highest value of CO_2 emissions was 25.604 for Luxemburg in 2005, while the lowest value was 1.200 for Costa Rica in 1997. Energy consumption has an average value of 3721.500 "(kg of oil equivalent per capita)", with a maximum value of 9428.811 recorded for Luxemburg in 2005 and the lowest value for Colombia in 2002. Natural resources rents are 1.273 on average, with a standard deviation of 2.244. The maximum value of natural resource rents is 17.220, recorded for the economy of Chile in 2006, while the lowest value is 0.0008, observed for the economy of Israel in 2003. Urbanization is relatively high, with a mean value of 75.825 percent. The maximum and minimum values are recorded for Belgium and Slovenia. Trade openness has a mean value of 91.580, with the maximum value of 388.120 percent observed for the economy of Luxemburg in 2021 and the lowest value of 18.125 percent for the Australian economy in 2002. The average per capita income in constant US $ is 32,753.570 for the sampled economies.

5.3. Regression results

Regression results are displayed in Table 4. Columns 2–4 include results extracted using the FEM. The results of column 2 show a positive and significant relationship between natural resources and environmental degradation. Our results suggest that natural resource extraction is one of the primary factors of environmental degradation in the case of the OECD economies. Recent studies 5,22] also demonstrated a long-run relationship between natural resource use and environmental degradation. Islam et al. [20] also showed that the depletion of natural resources is responsible for increased environmental degradation. The results of column 3 incorporating the square term of natural resources provide some interesting findings. The linear and square terms entered the estimated models positively and negatively, respectively, confirming the validity of the EKC hypothesis. This finding is new and interesting. Moving on from the traditional inverted U-shaped EKC hypothesis, we also included the cubic term of natural resources in the estimated model. The results in the final column indicate that the cubic term of natural resources has a positive coefficient in the estimated model. Taken together, the positive coefficient of the linear term, the negative coefficient of the square term, and the positive coefficient of the cubic term imply that the actual shape of the EKC hypothesis is N-shaped. It implies that natural resources will further degrade the quality of the environment in the long run after. In other words, the traditional inverted U-shaped EKC is not valid in the case of natural resources and environmental degradation. The policymaker of OECD economies needs to be vigilant to protect the environmental quality amid increased use of natural resources. Fig. 2 shows the N-shaped EKC hypothesis.

Energy consumption is positively and significantly connected with environmental degradation in the case of OECD economies. The energy consumption coefficient is positive and significant in all three estimated equations. The impact of energy use on environmental degradation is highest as can be seen from the coefficient value. Khan et al. [56] rightly commented that high energy use is detrimental to the quality of the environment. In such a scenario, renewable and clean energy sources could replace traditional energy sources. Fakher et al. [44] also highlighted the prominence of renewable energy in promoting environmental quality and empirically demonstrated that the consumption of renewable energy enhances environmental quality. This shift in how energy is generated would preserve the quality of the environment

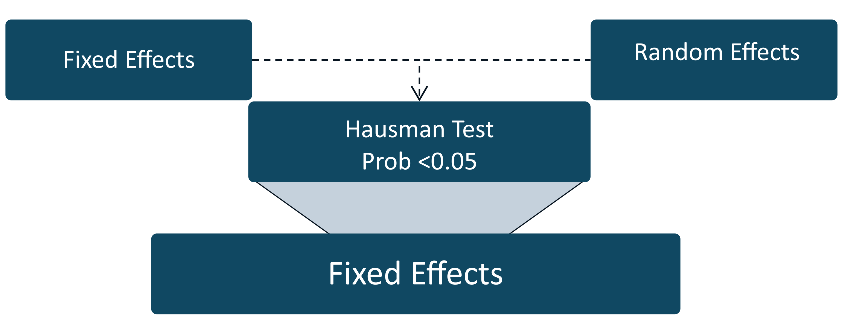

Fig. 1. Methods selection.

Table 3
Descriptive statistics.

Descriptives	CO_{2it}	$ENGC_{it}$	$NRSR_{it}$	URBN	$OPEN_{it}$	$PGDP_{it}$
Mean	8.119600	3721.500	1.273947	75.82520	91.58010	32,753.57
Maximum	25.60420	9428.811	17.22008	98.11700	388.1204	112,417.9
Minimum	1.200721	623.0283	0.000884	50.67500	18.12563	3953.587
Std. Dev.	4.309979	1795.458	2.244777	10.86794	54.28319	21,920.50
Observations	925	925	925	925	925	925

Note: Authors own calculation based on WDI database.

Table 4
Regression results.

Variables	Coefficients Fixed effects	Coefficients Fixed effects	Coefficients Fixed effects
$ENGC_{it}$	1.165*** (0.037)	1.213*** (0.036)	1.209*** (0.036)
$OPEN_{it}$	−0.110*** (0.015)	−0.0004* (0.0002)	−0.0004* (0.0002)
$URBN_{it}$	0.006*** (0.0006)	0.006*** (0.001)	0.006*** (0.001)
$PGDP_{it}$	−0.018 (0.019)	−0.048** (0.022)	−0.045** (0.022)
$NRSR_{it}$	0.019*** (0.003)	0.016*** (0.006)	0.028** (0.011)
$NRSR_{it}xNRSR_{it}$		−0.001*** (0.0003)	−0.003* (0.001)
$NRSR_{it}xNRSR_{it}xNRSR_{it}$			9.14E-05 (7.19E-05)
Constant	2.250 (0.337)	1.706 (0.275)	1.700 (0.275)
Diagnostic Tests		"Adj.R-Squared":0.997 "P (F-Test)": 0.000	"Adj.R-Squared":0.996 "P (F-Test)": 0.000

Note: "The asterisk (*) (**) and (***) shows 1 percent, 5 percent and 10 percent level of significance". In parenthesis, standard errors are reported.

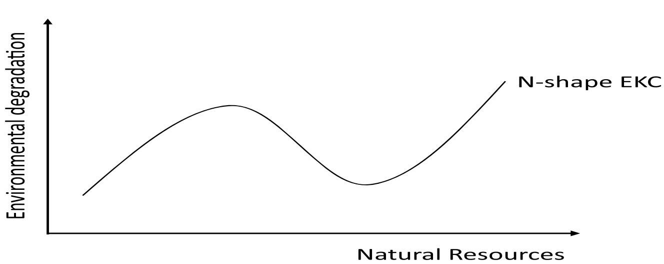

Fig. 2. Shape of the EKC Hypothesis.

without damaging the pace of economic growth.

Openness to trade is also an important factor for enhancing the quality of the environment. It has a negative and statistically significant coefficient in the estimated model, implying that trade openness has a beneficial influence on the quality of the environment. Our results supplement earlier studies (e.g., Lee et al., 2016) that argue openness to trade has a beneficial influence on the quality of the environment in high-income economies. The obtained results are in line with the technique which believes that trade openness enhances environmental quality due to the use of advanced and sophisticated technologies, which produce lower emissions levels as compared to traditional technologies. Most of the OECD economies fall into the high-income nations category; hence, a negative association between trade openness and environmental degradation was expected. The imports and exports of OECD economies are more likely to be based on clean and environmentally friendly technologies, causing little or no environmental damage.

Urbanization is one of the leading causes of deforestation and exerts substantial pressure on existing resources in urban areas. Studies (e.g., [5]) empirically show the adverse influence of urbanization on the quality of the environment. Urbanization degraded overall environmental quality and was statistically significant in all estimated models carrying a positive coefficient value. However, the negative consequences of urbanization on the quality of the environment could be reduced by properly managing the urbanization process. Currently, the OECD member states are already highly urbanized. Further urbanization is likely to jeopardize the quality of the environment. Therefore, policymakers and government authorities should monitor urbanization processes and lessen possible adverse consequences.

The negative coefficient of per capita GDP implies that higher income levels have improved the quality of the environment in the OECD economies. Increased income levels in a population boosts awareness about environmental degradation; hence, individuals behave more conscientiously. All three estimated models show high adjusted R-squared values, demonstrating excellent explanatory power. The overall model fitness test (F-test) confirms the suitability of the models (Fig. 3).

5.4. *Robustness testing*

We followed the GLS and TSLS methods for estimation purposes to verify whether our findings are sensitive to alternative estimating methodologies. Table 5 exhibits the results. The GLS results confirmed that the exploitation of natural resources is responsible for environmental degradation. Further, the results also found that the traditional EKC hypothesis is valid as the square term is negative, while the linear term is positive. Interestingly, the shape of the EKC hypothesis is N-shaped, as the cubic term is also positive in the estimated model. The TSLS-based results also validate earlier findings with a positive relationship between natural resource use and environmental degradation. Our results also provided evidence that the EKC hypothesis is valid and N-shaped for the relationship between the exploitation of natural resources and environmental degradation. The GLS and TSLS estimation results do not change our earlier results. Energy consumption and urbanization are still found to be the major threats to environmental degradation in OECD economies. Trade openness and increasing per capita incomes have improved the quality of the environment.

6. Causality analysis

We followed Dumitrescu and Hurlin's (2012) methodology to see the direction of the relationships among the variables. Table 6 shows the results. A bidirectional causality is witnessed between energy consumption, income, natural resources, and CO_2 emissions. Energy consumption is further bidirectionally related to income levels and natural resources. Trade openness, natural resources, and urbanization are also bidirectionally connected to income levels. A two-way causality is witnessed between trade openness and natural resources, urbanization and natural resources, and urbanization and trade openness. Finally, our results also show some one-way relationships among the variables. A one-way causality is seen between urbanization and CO_2 emissions, trade, and energy, and between urbanization and energy for the OECD economies.

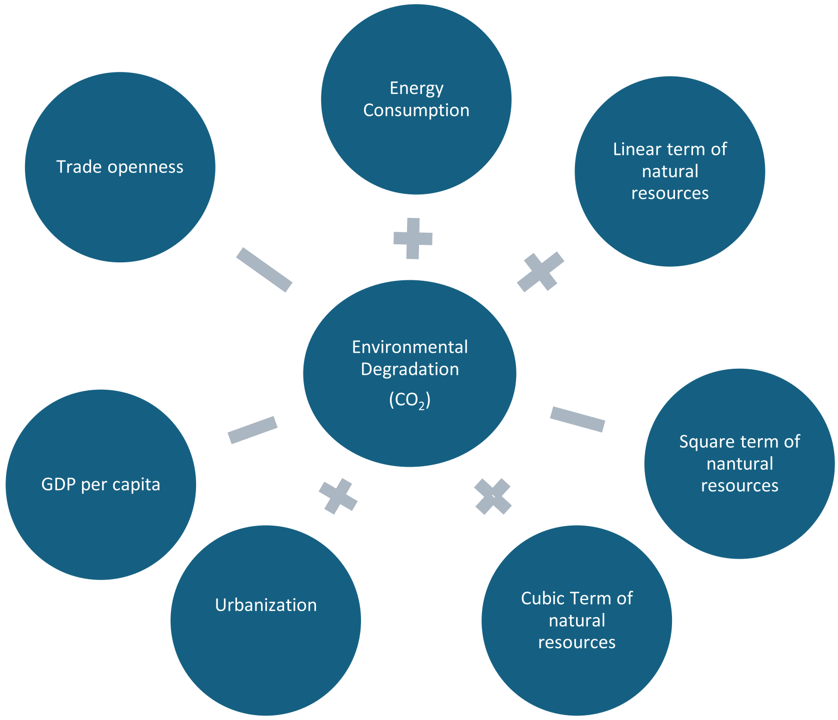

Fig. 3. Main findings.

Table 5
Results of sensitivity tests.

Variables	Coefficients GLS	Coefficients GLS	Coefficients GLS	Coefficients TSLS	Coefficients TSLS	Coefficients TSLS
$ENGC_{it}$	1.141*** (0.022)	1.155*** (0.022)	1.152*** (0.028)	1.144*** (0.059)	1.160*** (0.057)	1.168*** (0.054)
$OPEN_{it}$	−0.0009*** (0.0001)	−0.0009*** (0.0001)	−0.0009*** (0.0002)	−0.0005 (0.0004)	−0.0003 (0.0003)	−0.0004 (0.0003)
$URBN_{it}$	0.004*** (0.0008)	0.005*** (0.0007)	0.004*** (0.0006)	0.004*** (0.001)	0.004*** (0.0008)	0.005*** (0.0006)
$PGDP_{it}$	−0.019 (0.016)	−0.020 (0.016)	−0.017 (0.015)	−0.048 (0.039)	−0.052 (0.037)	−0.043 (0.034)
$NRSR_{it}$	0.012*** (0.003)	0.010** (0.005)	0.016** (0.007)	0.073*** (0.019)	0.066*** (0.014)	0.052*** (0.012)
$NRSR_{it}xNRSR_{it}$		−0.0008*** (0.0003)	−0.002* (0.001)		−0.0008*** (0.0002)	−0.001* (0.0009)
$NRSR_{it}xNRSR_{it}xNRS_{it}$			5.00E-05 (4.54E-05)			6.20E-05 (5.03E-05)
Constant	2.211 (0.185)	2.062 (0.179)	2.065 (0.209)	2.487 (0.451)	2.386 (0.384)	2.207 (0.345)
Diagnostic Tests	"Adj.R-Squared":0.998 "P (F-Test)": 0.000	"Adj.R-Squared":0.998 "P (F-Test)": 0.000	"Adj.R-Squared":0.996 "P (F-Test)": 0.000	"Adj.R-Squared":0.997 "P (F-Test)": 0.000	"Adj.R-Squared":0.997 "P (F-Test)": 0.000	"Adj.R-Squared":0.997 "P (F-Test)": 0.000

Note: "The asterisks (***), (**) and (*) indicate 1%, 5 % and 10% level of significance". In parenthesis, standard errors are shown.

6.1. Conclusions and implications

Our econometric analysis provided interesting findings about the relationship between natural resource use and environmental quality. First, it was found that exploiting natural resources harms environmental quality as it increases CO_2 emissions. It was also found that the established EKC hypothesis is valid for using natural resources and environmental degradation. Prior literature has only tested the EKC hypothesis for income levels and environmental degradation. Our results also show that the potential shape of the EKC hypothesis is N-shaped rather than the traditional inverted U-shape, a novel contribution to the literature. The N-shaped EKC hypothesis for the relationship between natural resource use and environmental degradation may attract the attention of researchers and policymakers in rethinking the relationship between natural resources and environmental degradation.

The study's main results show that the national choice for utilizing and managing natural resources will determine the intensity of climate change related risks. The degree and intensity of such risks are likely to guide OECD policymakers. Additionally, this study demonstrated that urbanization and energy consumption worsen the quality of the environment as the coefficient values of both variables are positive and significant. Finally, trade and growing income have enhanced environmental quality.

6.2. Implications of the research

Policy implications are the ultimate objective of all research studies. Therefore, based on the comprehensive and robust findings presented,

Table 6
DH causality analysis.

Null Hypothesis:	Zbar-Stat.	Prob.
ENG_{it} to CO_{2it}	3.22813***	0.0012
CO_{2it} to ENG_{it}	4.72828***	2.E-06
$PGDP_{it}$ to CO_{2it}	7.41192***	1.E-13
CO_{2it} to $PGDP_{it}$	3.70086***	0.0002
NRS_{it} to CO_{2it}	6.03877***	2.E-09
CO_{2it} to NRS_{it}	5.14428***	3.E-07
$OPEN_{it}$ to CO_{2it}	3.32784***	0.0009
CO_{2it} to $OPEN_{it}$	3.64112***	0.0003
URB_{it} to CO_{2it}	11.1958***	0.0000
CO_{2it} to URB_{it}	0.27847	0.7807
$PGDP_{it}$ to ENG_{it}	8.35342***	0.0000
ENG_{it} to $PGDP_{it}$	0.60841	0.5429
NRS_{it} to ENG_{it}	2.25380**	0.0242
ENG_{it} to NRS_{it}	5.93375***	3.E-09
$OPEN_{it}$ to ENG_{it}	8.07957***	7.E-16
ENG_{it} to $OPEN_{it}$	1.53010	0.1260
URB_{it} to ENG_{it}	17.1275***	0.0000
ENG_{it} to URB_{it}	−0.28951	0.7722
NRS_{it} to $PGDP_{it}$	4.78328***	2.E-06
$PGDP_{it}$ to NRS_{it}	11.9540***	0.0000
$OPEN_{it}$ to $PGDP_{it}$	2.47147**	0.0135
$PGDP_{it}$ to $OPEN_{it}$	7.17929***	7.E-13
URB_{it} to $PGDP_{it}$	7.33921***	2.E-13
$PGDP_{it}$ to URB_{it}	3.52174***	0.0004
$OPEN_{it}$ to NRS_{it}	3.81710***	0.0001
NRS_{it} to $OPEN_{it}$	3.69925***	0.0002
URB_{it} to NRS_{it}	8.05460***	9.E-16
NRS_{it} to URB_{it}	3.03498***	0.0024
URB_{it} to $OPEN_{it}$	11.7142***	0.0000
$OPEN_{it}$ to URB_{it}	3.18420***	0.0015

Note: "The asterisk (**), (***) shows significance level at 5 and 10 percent".

we suggest that the following areas could be considered for future policy formulation.

1) The natural resources sector needs significant attention from policymakers in the OECD economies as the N-shaped EKC hypothesis suggested that increased natural resource extraction will degrade the environment further. In other words, the traditional EKC hypothesis, which suggests that the environmental quality will be improved automatically in the long run, is not valid concerning the relationship between natural resources and environmental degradation in the case of OECD economies.
2) The results show that growing urbanization rates present a real threat to the environment. However, all OECD economies are already highly urbanized and well-developed. Further urbanization activities need to be closely monitored.
3) Trade has enhanced the quality of the environment based on obtained results, indicating that the OECD economies may be producing goods using environmentally friendly technologies. The study recommends that the OECD economies switch to clean and green technologies for production, particularly in export-oriented industries. The go-green strategy is the only option for the OECD economies to protect the quality of the environment from further degradation.
4) Regarding energy consumption, the OECD economies need to focus on encouraging the use of green and renewable energy sources to maintain the speed of growth without the costs of environmental degradation. In today's world, economies are heavily dependent on increased energy use. However, increased energy use is also responsible for the increased emissions which is undesirable. Therefore, alternative sources of energy must be exploited to protect the environment.

6.3. Limitations and future research avenues

This paper has attempted to study the influence of natural resources on the quality of the environment comprehensively. However, as outlined below, some unavoidable limitations exist.

1) The results are only valid for the OECD economies as these countries are similar in terms of their economic parameters. Hence, the results can only be generalized for economies with similar characteristics.
2) The study only focuses on the main drivers of environmental degradation. However, environmental degradation has several determinants as it is an extremely complex phenomenon. Therefore, future research studies could focus on including other relevant determinants of environmental degradation in their models.
3) Future research studies are advised to use additional proxies for environmental degradation, such as "pressures on nature, environmental vulnerability, ecological footprints, and adjusted net saving." These additional indices will provide more robust evidence about environmental quality and its prominent determinants.
4) Future studies could also use more sophisticated tools like panel cointegration or GMM estimation methods to determine the robust relationship between environmental degradation and its determinants. This study has only used traditional methods of estimation.

CRediT authorship contribution statement

Muhammad Tahir: Methodology, Formal analysis. **Abdulrahman A. Albahouth:** Validation, Project administration, Conceptualization. **Mohammed Jaboob:** Software, Resources, Methodology. **Al Jameel Osama:** Visualization, Methodology, Data curation. **Umar Burki:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare there is no conflict of interests.

Data availability

Data will be made available on request.

Appendix

Table A1
Hausman test.

Models	Test-value	Prob.	Decision
1	27.578	0.000	FEM is Suitable
2	26.612	0.000	FEM is Suitable
3	27.400	0.000	FEM is Suitable

Table A2

Table A2
Pesaran CD Test.

Models	Test-value	Prob.	Decision
1	0.170	0.864	Cross-sectional independence
2	0.191	0.848	Cross-sectional independence
3	0.195	0.845	Cross-sectional independence

Table A3
VIF testing (Multicollinearity).

Variables	Uncentered VIF	Centered VIF	Conclusion
$ENGC_{it}$	3.714408	1.370626	No Multicollinearity
$PGDP_{it}$	3.502046	2.066460	No Multicollinearity
$OPEN_{it}$	1.888624	1.877724	No Multicollinearity
$URBN_{it}$	1.410359	1.211974	No Multicollinearity
$NRSR_{it}$	1.010774	1.010501	No Multicollinearity

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