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An Empirical Assessment of Oil, Natural Gas, Mineral, and Forest Rents on CO_2 Emissions in Saudi Arabia

Haider Mahmood*

Department of Finance, College of Business Administration, Prince Sattam bin Abdulaziz University, 11942 Alkharj, Saudi Arabia

* Correspondence: Haider Mahmood (haidermahmood@hotmail.com)

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Abstract: The role of natural resource rents (NRR) in driving environmental degradation has attracted increasing scholarly attention, particularly in resource-dependent economies. In the case of Saudi Arabia, where oil and gas extraction constitutes a substantial proportion of GDP, the relationship between resource rents and environmental quality warrants rigorous investigation. This study examines the effects of oil, natural gas, mineral, and forest rents on carbon dioxide (CO_2) emissions within the framework of the Environmental Kuznets Curve (EKC), over the period 1970–2023. Employing optimal lag selection criteria, augmented Dickey–Fuller and Phillips–Perron unit root tests were applied to ensure the stationarity of variables, followed by Johansen cointegration analysis to establish the existence of long-run relationships among them. The EKC hypothesis is empirically validated, with a turning point identified at 65,914 Saudi Riyals (SR) in the long term and 65,912 SR in the short term, indicating a non-linear relationship between economic growth and CO_2 emissions. Oil Rents (OR) were found to exert statistically significant positive effects on CO_2 emissions in both the short and long run, suggesting that oil dependence remains a critical driver of environmental degradation. Conversely, natural gas, mineral, and forest rents exhibited statistically insignificant impacts in the long run, although short-run analyses revealed a positive but marginally significant influence of natural gas and forest rents. These findings underscore the asymmetric environmental implications of different types of resource rents. Policy implications point toward the urgent need to diversify the economic base away from oil dependency and enhance regulatory frameworks to mitigate the ecological costs of resource exploitation. By integrating the EKC hypothesis with disaggregated rent variables, this study contributes to the nuanced understanding of resource–environment dynamics in hydrocarbon-reliant economies.

Keywords: Natural resource rents (NRR); Carbon emissions; Environmental Kuznets Curve (EKC); Economic growth; Resource dependence; Saudi Arabia

1. Introduction

NRR is significantly contributing to economic growth in resource-rich countries. However, growing empirical evidence suggests that NRR is a threat to environmental sustainability, as the extraction, processing, and consumption of natural resources are usually responsible for carbon emissions and ecological degradation. Despite a large body of literature that has explored the relationship between aggregate NRR and environmental degradation in global and regional panels, the studies exploring the environmental effects of disaggregated sources of NRR are scant (Jia et al., 2024; Sun et al., 2024). Particularly, the investigation of the relationship between disaggregated sources of NRR and environmental degradation is missing in the Saudi literature. Addressing this gap, the current study aims to empirically examine the effects of oil, natural gas, mineral, and forest rents on CO_2 emissions in the resource-abundant economy of Saudi Arabia by using a long period from 1970 to 2023 and by applying the robust Autoregressive Distributive Lag (ARDL) econometric technique. The study hypothesizes the positive effects of all NRR sources on CO_2 emissions in the resource-rich Saudi economy. By doing disaggregated analyses, this study aims to explore a research question: which resources are most responsible for environmental degradation in the long and short run?

Saudi Arabia is a natural resource-rich economy carrying abundant oil, natural gas, and other mineral reserves. Thus, this economy is highly dependent on NRR and particularly on OR. The OR percentage of Saudi GDP was 87% in the year 1979. Afterward, the OR's dependence declined. However, the OR was recorded at 41.7% of GDP on average during the decade of 2000-2010 and 31.7% of GDP on average during the decade of 2010-2020 (Saudi Central Bank, 2025). The NRR from other resources is not too high. For instance, NRR from natural gas, other minerals, and forests are 0.71%, 0.02%, and 0.001% of the GDP during the sample period on average, respectively (Saudi Central Bank, 2025). The NRR percentage of GDP shows a heavy reliance of the Saudi income on natural resources, which can be responsible for environmental degradation due to the fossil fuel dependence of the Saudi economy (World Bank, 2025). Consequently, Saudi Arabia stands in 10th position in the world as per total CO_2 emissions (World Population Review, 2025).

In 2016, Saudi Arabia launched Vision 2030, carrying many environmental targets (Government of Saudi Arabia, 2025). One of the most important targets of Vision 2030 is to diversify the Saudi economy from oil to tourism and other clean sectors for sustainable economic growth and the environment (Pratiwi & Muslikhati, 2024). For this purpose, renewable energy projects with a target of 5.9 gigawatts of renewable energy by the year 2030 are targeted to reduce the reliance on fossil fuels. Furthermore, some recycling programs have been targeted in major cities to reduce the environmental impact of waste and to convert waste into energy. Moreover, stricter regulations are targeted to reduce air and marine pollution (National Platform, 2024). In addition, Saudi Arabia is aligning the objectives of Vision 2030 with the Sustainable Development Goals (SDGs) (Alharthi et al., 2019). Despite these efforts, the reliance of the Saudi economy on NRR is still very high, and the present research aims to empirically test the individual effects of oil, natural gas, mineral, and forest rents on CO_2 emissions in the resource-rich economy of Saudi Arabia.

2. Literature Review

There is abundant literature on the environmental effects of NRR since the development of the Natural Resource Curse Hypothesis (NRCH). However, the present research focuses on the recent studies, which have been published in the current decade, to review the latest developments in this topic. This approach would help in tracing the literature gap after discussions of the recent advancements and trends. Accordingly, the study could contribute to the natural resource literature meaningfully and significantly. Moreover, this section is divided into subsections to differentiate the panel, regional, and time series literature.

2.1 Theoretical Literature

Natural resources can be a curse for an economy's growth, as other sectors of the economy can be disturbed due to the shifting of production inputs from these sectors to the natural resource sector. Moreover, the appreciation of the currency due to natural resource trade may affect the trade from other sectors, which is termed Dutch Disease (Sachs & Warne, 1995). The extraction of natural resources could also be harmful to environmental sustainability (Lv et al., 2024). Natural resources could have environmental problems at all stages, i.e., extraction, production, consumption, etc. For instance, the extraction of oil, natural gas, and minerals is an energy-intensive activity (Svensson et al., 2020). Thus, their extraction, refining, and processing could have environmental problems (Ragothaman & Anderson, 2017). Moreover, flaring and venting during oil and natural gas production would be responsible for methane and CO_2 emissions (Soltanieh et al., 2016). Furthermore, oil products are heavily utilized in transportation and electricity production. Forest rents are responsible for deforestation, which can release CO_2 emissions from trees and soil carbon sinks, and would be responsible for environmental damage (Pan et al., 2011).

2.2 Global Studies

Sun et al. (2024) analyzed global CO_2 emissions from 1990 to 2021 and revealed that NRR from the oil and forest sectors contributed to higher emissions. Oppositely, natural gas rents had a mitigating effect. Technological innovation and Renewable Energy Consumption (REC) also played a positive role in cutting emissions. In contrast, economic expansion and population growth were identified as key drivers of increased emissions. In a large panel of 214 countries, Wang et al. (2024a) validated the Environmental Kuznets Curve (EKC) and geopolitical tensions and food insecurity aggravated carbon emissions. Conversely, improvements in institutional quality and shifts toward cleaner energy sources reduced emissions. Remarkably, NRR did not show a significant effect on emissions. Focusing on 152 countries between 2002 and 2018, Li et al. (2024a) emphasized that controlling corruption enhanced environmental quality in regions with initially poor environmental standards. But NRR had a detrimental effect in areas with already strong environmental performance. Moreover, energy intensity worsened environmental outcomes, and REC helped mitigate its adverse impact.

Exploring data from 159 nations from 2000 to 2019, Bosah et al. (2023) concluded that energy use with rising economic development intensified ecological degradation worldwide. This effect was particularly evident in Asia, where NRR further exacerbated environmental harm. Wang et al. (2023) investigated 66 countries from 1993 to 2018 and observed that the adoption of robotics contributed to lower Carbon Intensity (CI) under conditions of low NRR. However, at higher NRR levels, robot use paradoxically led to greater CI. A similar threshold effect was noted for corruption control in the robot-CI relationship. Lv et al. (2024), studying 102 emerging economies between 2006 and 2016, identified a negative association between NRR and environmental quality. Nonetheless, Information and Communication Technologies (ICT) were found to buffer this effect, which promoted efficient resource use.

Nwani et al. (2023), in their analysis of 45 developing nations from 1995 to 2017, found that NRR, income growth, and energy intensity were associated with rising emissions. In contrast, Shahbaz et al. (2024), focusing on the 30 most polluted countries over the 1995-2021 period, reported that REC, environmental taxation, and rents from coal and minerals were effective in reducing CO_2 emissions. But fossil fuel consumption remained a major pollutant. In a study of the top 10 emitting countries from 2004 to 2018, Shang et al. (2024) found that REC contributed positively to environmental quality. Yet, both financial inclusion and NRR were linked to higher levels of ecological degradation. Lin et al. (2024) analyzed 36 economies from 2000 to 2020 and introduced the Productive Capacity Index (PCI) as a novel proxy for economic cycles. The authors concluded that geopolitical risk, PCI, and NRR collectively intensified CO_2 emissions. On the other hand, globalization and REC had a dampening effect. Li et al. (2024b) examined the association between carbon emissions, geopolitical risk, and NRR in 38 countries from 2002 to 2020 and confirmed the EKC hypothesis. Moreover, geopolitical instability raised emissions, and NRR exhibited a U-shaped effect on carbon emissions.

2.3 Regional Studies

Zhou et al. (2024) explored the energy productivity, institutional quality, and emissions nexus in E7 economies in quantile analysis and revealed that NRR contributed to emission reductions. Additionally, REC and energy productivity amplified this positive environmental effect. Institutional quality also played a mitigating role at specific quantile levels. In a study on G-10 nations from 1995 to 2018, You et al. (2023) highlighted that policy uncertainty exacerbated ecological footprints, while NRR and a well-structured economy acted as counterbalancing forces. Zhe et al. (2024) assessed the environmental effects of FinTech, NRR, and green innovations across G7 and G11 economies. Their results indicated that FinTech supported emissions reduction by broadening access to green finance and improving market efficiency. Moreover, green innovations exhibited an even greater capacity to reduce CO_2 emissions. In contrast, NRR in these economies was associated with increased emissions. Jia et al. (2024) explored G-20 countries from 2000 to 2021 and confirmed the EKC hypothesis. The positive environmental contributions of NRR from gas, oil, and forest resources were reported with the provided fiscal space for sustainability efforts. In addition, FinTech and ICT were also identified as instrumental in reducing emissions.

Soni & Manogna (2025) analyzed the E7 and G7 economies from 2004 to 2021 and reported that both NRR and Foreign Direct Investment (FDI) contributed to higher carbon emissions. Nonetheless, financial inclusion fostered environmentally friendly outcomes in E7 nations. Amin et al. (2025) substantiated these results for BRICS economies. For instance, economic growth and NRR contributed to emissions, while green finance and R&D emerged as significant mitigating factors. In a reassessment of the BRICS bloc from 1990 to 2020, Udeagha & Muchapondwa (2023) highlighted the emissions-reducing potential of green finance, FinTech, and energy innovations. Yet, economic advancement and NRR were shown to elevate emissions. Their findings also validated the EKC hypothesis. Çoban et al. (2025) demonstrated the role of innovation in lowering emissions and reducing ecological footprints in EU-14 countries. Although NRR raised both pollution proxies.

Dao et al. (2024) evaluated the environmental consequences of resource diversification in selected OECD nations from 2009 to 2019 and found that diversification adversely affected environmental quality in countries with stronger environmental conditions. Işık et al. (2024) re-analyzed OECD data from 2001 to 2020 and concluded that both REC and internet usage helped reduce emissions. Though mineral rents had the opposite effect. Wahab et al. (2024) extended the dataset of OECD countries from 1990 to 2022 and identified NRR as a driver of emissions. On the other hand, trade openness and globalization served as counterweighing factors. The authors further stressed the importance of environmental governance in sustaining emission reductions. Achuo et al. (2023) examined Africa from 1996 to 2020 and reported that NRR increased pollution levels. However, good governance served as a crucial factor in mitigating the environmental impact of NRR. Kwakwa & Aboagye (2024) re-investigated Africa from 2002-21 and found that NRR accelerated carbon emissions, and some parameters of institutional quality mitigated emissions by playing their moderating roles.

Shuayb et al. (2024) focused on 10 resource-rich African economies from 1990 to 2021 and substantiated that economic development, NRR, and energy intensity contributed to environmental degradation. However, REC and the rule of law were identified as countermeasures that helped reduce environmental harm. In a study of nine Arab nations from 1996 to 2019, Fatah & Altaee (2024) explored the environmental role of political stability, globalization, industrialization, and NRR and concluded the adverse environmental impact of these factors. Nwani et al. (2024) provided further insight by examining 20 oil-rich countries and found a U-shaped relationship between NRR and emissions. Thus, at higher levels of resource dependency, NRR was responsible for a carbon-curse phase. Mahmood et al. (2023) analyzed 17 MENA economies from 2000 to 2019 and corroborated the EKC hypothesis. Moreover, oil rents remained a dominant source of emissions in local and neighboring economies. In the analysis of South Asia, Khan et al. (2024a) explored the impacts of REC, urbanization, and Financial Market Development (FMD) on emissions and concluded that REC reduced emissions. Conversely, urbanization and FMD intensified environmental pressures.

2.4 Country-Specific Studies

Wang et al. (2024b) investigated China from 1984 to 2021 and highlighted the effectiveness of public-private collaboration in energy investments and environmental technologies to reduce CO_2 emissions. Their findings further indicated that NRR and technological advancements reinforced these positive effects indirectly. But the direct effect of NRR contributed to higher emissions. Huang & Guo (2022) re-examined China from 1995 to 2017 and found that NRR and the transport sector were major contributors to increased CO_2 emissions. Moreover, green investments initially intensified emissions but later led to improvements in environmental outcomes. Sahoo et al. (2024) analyzed India from 1990 to 2022 and identified tourism, NRR, and policy uncertainty as potential drivers of a growing ecological footprint. Conversely, REC mitigated it.

Khan et al. (2024b) assessed Algeria from 1980 to 2019 and found that technological innovation, NRR, and FMD reduced emissions, which helped promote sustainable development. Rehman et al. (2024) examined Pakistan from 1971 to 2019 and corroborated an asymmetric effect of NRR on environmental outcomes, which suggested that the impact of resource rents on emissions varied across different economic conditions. Udemba et al. (2023) examined Norway from 1970 to 2018 and found that fuel consumption raised CO_2 emissions. Interestingly, income growth and NRR supported environmental improvements. Further, a nonlinear relationship between FDI and emissions was reported, which implied that FDI contributed positively to environmental quality after a threshold point. In contrast, Qamruzzaman (2024) found a deteriorating impact of NRR, institutional quality, and FDI on environmental sustainability in Cambodia, as all three factors were associated with increased CO_2 emissions. Additionally, FMD was responsible for higher emission levels.

Alhassan & Kwakwa (2022) evaluated Ghana's environmental performance from 1971 to 2018 and determined that NRR was a source of rising emissions. Meanwhile, government debt exhibited a dual-phase effect, which initially improved environmental quality but later contributed to environmental degradation. Shi et al. (2023), in their study of Saudi Arabia covering 1990 to 2019, reported that enhancements in FMD and REC effectively reduced emissions. However, aggregated NRR and economic expansion were identified as primary contributors to increased emissions. Lastly, Caglar et al. (2024) examined Brazil from 1970 to 2021 and reported that both NRR and FDI posed challenges to environmental sustainability by increasing pollution. On a positive note, the adoption of cleaner energy sources was shown to significantly enhance environmental quality.

3. Methodology

The EKC theory suggested a nonlinear connection between emissions and economic progress (Grossman & Krueger, 1991), as economic growth can increase emissions at first and reduce them at a later stage. NRR can help trace the EKC in a resource-rich Saudi economy. For instance, the NRCH explains that NRR can reduce exports and income from other sectors of the economy and could harm the GDP growth (Avom & Carmignani, 2010; Sarmidi et al., 2013), which can be termed the Dutch Disease phenomenon. The consequent reduced economic growth may reduce energy demand and emissions. On the other hand, NRR contributes significantly to the GDP of the Saudi economy, and the increasing GDP from the pollution-oriented natural resource sector can accelerate energy consumption and emissions, which can delay the first phase of the EKC, and is called the scale effect. However, NRR can also achieve technique and composition effects if NRR could be invested in technological and industrial transformations. On the whole, the literature dictates that NRR could have environmental concerns for an economy by enhancing pollution and disturbing the ecosystem (Zakari & Oluwaseyi Musibau, 2023). Following this argument, a lot of recent literature has confirmed the environmental consequences of aggregated NRR (Fatah & Altaee, 2024; Zhe et al., 2024). However, recent studies emphasize the importance of analyzing disaggregated NRR to better understand the comparative impact of each source on environmental degradation (Jia et al., 2024; Sun et al., 2024). Following this stream of literature and the EKC hypothesis, we hypothesize the adverse environmental effects of oil, natural gas, mineral, and forest rents in a resource-rich Saudi economy in the following way:

$$LCO2_t = f\,(LGDPC_t, LGDPC_t^2, LOR_t, LNGR_t, LMR_t, LFR_t) \quad (1)$$

$LCO2_t$ is the natural log of per capita CO_2 emissions, and data is collected from the Global Carbon Atlas (2025).

LOR_t, $LNGR_t$, LMR_t, and LFR_t are natural logs of oil, natural gas, mineral, and forest rents percentages of the GDP, respectively. $LGDPC_t$ is per capita GDP, and $LGDPC_t^2$ represents the square of $LGDPC_t$. Data on these variables is collected from the World Bank (2025). All data is collected for the period 1970-2023. All variables are taken into logarithmic forms, as log transformation can reduce the impact of outliers in magnitudes in variables, which could allow for more balanced estimation and reduce potential distortion in regression results. For instance, logging would help stabilize the variance of variables and improve the robustness and reliability of statistical inferences. Moreover, logging variables could help to interpret coefficients in terms of elasticities. To estimate the turning point of the EKC in Eq. (1), we take the partial derivative of $LCO2_t$ with respect to $LGDPC_t$, assuming a b_1 slope of $LGDPC_t$ and a b_2 slope of $LGDPC_t^2$:

$$\frac{dLCO2_t}{dLGDPC_t} = b_1 + 2b_2 LGDPC_t \tag{2}$$

Then, we set the derivative equal to zero to find the maximum point and solve for $LGDPC_t$.

$$LGDPC_t = -\frac{b_1}{2b_2} \tag{3}$$

Lastly, we take the exponent of both sides of Eq. (3) to find the absolute value of GDP per capita.

$$GDPC_t = \text{exponent}\left(-\frac{b_1}{2b_2}\right) \tag{4}$$

Eq. (4) will be utilized to find the turning point of the EKC. The estimation of Eq. (1) requires the testing of the unit root to ensure the normality and stationarity of the series to be utilized in cointegration analyses. The present study utilizes the four test statistics of Ng & Perron (2001) to verify the stationarity of the series in the following way:

$$MZ_a^d = \left[\frac{Y_T^d}{T}\right]^2 /2K - f_0/2K \tag{5}$$

$$MSB^d = \left[\frac{k}{f_0}\right]^{1/2} \tag{6}$$

$$MZ_t^d = MZ_a^d . MSB^d \tag{7}$$

$$MPT_T^d = [c^2 . K + \frac{1-c}{T}] . \frac{Y_T^d}{f_0} \tag{8}$$

The Ng-Perron test is preferred due to its superior statistical properties over the Augmented Dickey-Fuller (ADF) or Phillips-Perron (PP) tests in dealing with small or moderate sample sizes. ADF and PP tests usually suffer from size distortions and low power. However, the Ng-Perron test improves reliability. This test incorporates Generalized Least Squares (GLS) detrending, which enhances the ability of this test to correctly identify stationarity. In addition, MZα, MZt, MSB, and MPT statistics are designed to account for serial correlation and heteroscedasticity. Therefore, the Ng-Perron test provides a more robust and reliable framework for determining the stationarity properties of the data. After testing the unit root, the study may proceed to the ARDL technique to verify the short- and long-run relationships. Following Pesaran et al. (2001), the ARDL framework may be defined as follows:

$$\begin{aligned} \Delta LCO2_t = a_{10} + a_{11}LCO2_{t-1} + a_{12}LGDPC_{t-1} + a_{13}LGDPC_{t-1}^2 + a_{14}LOR_{t-1} + a_{15}LNGR_{t-1} + \\ + a_{16}LMR_{t-1} + a_{17}LFR_{t-1} + \textstyle\sum_{i=1}^{j} a_{18i}\Delta LCO2_{t-i} + \sum_{i=0}^{j} a_{19i}L\Delta GDPC_{t-i} + \sum_{i=0}^{j} a_{20i}LGDPC_{t-1}^2 + \\ \textstyle\sum_{i=0}^{j} a_{21i}\Delta LOR_{t-i} + \sum_{i=0}^{j} a_{22i}\Delta LNGR_{t-i} + \sum_{i=0}^{j} a_{23i}\Delta LMR_{t-i} + \sum_{i=0}^{j} a_{24i}\Delta LFR_{t-i} + e_{11t} \end{aligned} \tag{9}$$

Eq. (9) will be regressed after choosing the optimal lag length. Then, the Bound test will be employed on the null hypothesis of $a_{11}=a_{12}=a_{13}=a_{14}=a_{15}=a_{16}=a_{17}=0$ to verify the cointegration. The estimated F-values more than the upper bound could reject the null hypothesis and confirm the cointegration. Then, the long-run effects will be estimated by normalizing the lagged-level coefficients. The lagged-differenced variables will be chosen with optimal lag lengths to remove the endogeneity issue. Afterward, Eq. (9) could be transformed into an error correction model by replacing lagged-level variables with $ECT_{t\text{-}1}$ in the following way:

$$\Delta LCO2_t = g_1 ECT_{t-1} + \sum_{i=1}^{j} a_{18i}\Delta LCO2_{t-i} + \sum_{i=0}^{j} a_{19i}\Delta LGDPC_{t-i} + \sum_{i=0}^{j} a_{20i} LGDPC_{t-1}^2 + \sum_{i=0}^{j} a_{21i}\Delta LOR_{t-i} + \sum_{i=0}^{j} a_{22i}\Delta LNGR_{t-i} + \sum_{i=0}^{j} a_{23i}\Delta LMR_{t-i} + \sum_{i=0}^{j} a_{24i}\Delta LFR_{t-i} + e_{12t} \quad (10)$$

In Eq. (10), the coefficient (g_1) should be negative to ensure the short-run relationships in the model and to capture the speed of adjustment. Later, short-run effects would be explained from estimations of the a_{ij} coefficients.

4. Data Analysis

Table 1 displays unit root results, and all series at their levels show non-stationary behavior. However, all variables at their first differences show stationary behavior. Thus, the order of integration is one, and it is fine to proceed to cointegration analysis.

Table 1. Ng-perron unit root test

Series	MZa	MZt	MSB	MPT
$LCO2_t$	-1.7444	-0.7687	0.4407	11.7290
$LGDPC_t$	-11.2051	-2.3524	0.2099	8.2075
$LGDPC_t^2$	-11.0547	-2.3367	0.2114	8.3159
LOR_t	-11.0215	-2.3157	0.2101	8.4282
$LNGR_t$	-7.4375	-1.9271	0.2591	12.2547
LMR_t	-14.3682	-2.6681	0.1857	6.4121
LFR_t	-12.9602	-2.5376	0.1958	7.0766
$\Delta LCO2_t$	-24.0090***	-3.4516***	0.1437***	3.8743***
$\Delta LGDPC_t$	-18.3611**	-3.0096**	0.1639**	5.0869**
$\Delta LGDPC_t^2$	-18.5586**	-3.0263**	0.1631**	5.0309**
ΔLOR_t	-24.9157***	-3.4454***	0.1383***	4.1547***
$\Delta LNGR_t$	-24.6186***	-3.5055***	0.1424***	3.7191***
ΔLMR_t	-18.1791**	-3.0069**	0.1654**	5.0616**
ΔLFR_t	-23.5545**	-3.4165**	0.1451**	3.9605**

Note: ** and *** demonstrate stationarity of the series at 5% and 1% levels, respectively.

Table 2. Bound test and diagnostics tests

Dependent	F-Value	Heteroscedasticity	Serial Correlation	Normality	Functional
$\Delta LCO2_t$	4.0566	1.1904 (0.3438)	0.2146 (0.8085)	0.0878 (0.9570)	2.1451 (0.1399)
Level of significance	10%	5%	1%		
Critical Bounds	1.99-2.94	2.27-3.28	2.88-3.99		

Note: P-values are mentioned in parentheses.

In Table 2, the Bound test is applied, including the selected optimal lag length. F-value = 4.0566 is more than the upper bound at 1%. Thus, the model is proven for cointegration. Moreover, p-values from all diagnostics are more than 0.1, which shows that the model is free from any econometric problem. Thus, the long-run effects can be estimated and interpreted.

Table 3 shows the long-run coefficients. $LGDPC_t$ and $LGDPC_t^2$ carry positive and negative coefficients, respectively. Thus, the EKC hypothesis has been substantiated. The turning point of the model is 65,914 SR [exponent of -(417.3780/2/-18.8074)]. The average Saudi GDP per capita in the sample period is observed as greater than the estimated turning point. Thus, long-run economic growth has pleasant environmental effects.

Table 3. Long run estimates from the ARDL model

Variables	Coefficient	Standard Error	t-Statistic	P-Value
$LGDPC_t$	417.3780**	181.9909	2.2934	0.0301
$LGDPC_t^2$	-18.8074**	8.1618	-2.3043	0.0295
LOR_t	0.2750***	0.0748	3.6788	0.0000
$LNGR_t$	-0.0896	0.2073	-0.43249	0.6690
LMR_t	0.0017	0.0255	0.0667	0.9473
LFR_t	-0.1993	0.1537	-1.2967	0.2061
Intercept	23.1590**	10.1396	2.2840	0.0308

Note: ** and *** show statistically significant coefficients at 5% and 1% levels, respectively.

The coefficient of LOR_t is positive, and its p-value is less than 0.01. Thus, raising OR accelerates CO_2 emissions at a 1% level of significance. The elasticity coefficient of LOR_t shows that a 1% increase in OR is responsible for increasing 0.2750% emissions. However, the long-run effects of natural gas, mineral, and forest rents are found to be statistically insignificant, with p-values of their coefficients more than 0.1.

In Table 4, the coefficient of ECT_{t-1} is negative, which reflects that any short-run oscillations would be adjusted to the long-run path. The EKC has also been corroborated with the coefficients of $\Delta LGDPC_t$ and $\Delta LGDPC_t^2$. The turning point is 65,912 SR [exponent of -(182.211/2/-8.2106)]. The average GDP per capita in the sample period is greater than the estimated turning point. Thus, the economic growth of Saudi Arabia is mitigating CO_2 emissions. The effects of NRR from all investigated sources on CO_2 emissions are positive, except for mineral rents. Thus, most sources of NRR contribute to carbon emissions.

Table 4. Short run estimates from the ARDL model

Variables	Coefficient	Standard Error	t-Statistic	P-Value
$\Delta LCO2_{t-1}$	0.5634***	0.1038	5.4280	0.0000
$\Delta LGDPC_t$	182.2110***	45.6081	3.9951	0.0000
$\Delta LGDPC_t^2$	-8.2106***	02.0609	-3.9854	0.0000
ΔLOR_t	0.1201***	0.0381	3.1350	0.0000
$\Delta LNGR_t$	0.0391***	0.0091	4.2896	0.0000
ΔLMR_t	0.0007	0.0005	1.3981	0.1744
ΔLFR_t	0.0869***	0.0251	3.4566	0.0000
ECT_{t-1}	-0.3849***	0.0778	-4.9527	0.0000

Note: *** shows statistically significant coefficients at 1% level.

5. Discussions

In the EKC results, the average Saudi GDP per capita is greater than the turning point. Thus, the economic growth of Saudi Arabia is helping reduce CO_2 emissions. This result reflects the Saudi efforts towards increasing the tourism sector and other cleaner sectors, which are less pollution-oriented compared to the natural resource sector. OR increases emissions in both the long and short runs. The findings corroborate the fact that the GDP of Saudi Arabia consists of 37.8% OR. So, increasing OR is raising GDP and aggregate demand in the Saudi economy, which would result in increasing fossil fuel consumption. Moreover, OR would also raise environmental degradation, as most of the electricity production and industrial production in Saudi Arabia depend on fossil fuels. Further, most of the transport sector depends on oil and its derivative products, which release carbon emissions extensively. In addition, the extraction and production of oil are pollution-oriented, as oil extraction machines use fossil fuels to extract oil from oil sands and deep-water reserves. Furthermore, the oil refining process uses many chemicals and a large amount of energy, which releases a significant amount of CO_2 emissions. Finally, yet importantly, oil usage in the petrochemical industry is highly pollution-oriented. So, the oil from production to consumption is responsible for increasing CO_2 emissions.

The long-run effects of natural gas, mineral, and forest rents are found to be statistically insignificant. The findings of the present research recall that the Saudi economy is extensively dominated by the oil sector, which contributes the largest share to GDP, government revenues, and export earnings. However, natural gas, minerals, and forest rents contribute marginally to GDP. For instance, the NRRs from the natural gas, mineral, and forest sectors are less than 1% of Saudi GDP. Thus, the insignificant contribution of these NRRs could not affect CO_2 emissions in the long run. Historically, the Saudi government has prioritized the oil industry and paid less strategic attention to other natural resources in national development plans. Though Vision 2030 recently focuses on diversifying resource rents, natural gas has gained attention in recent years for electricity generation. Still, natural gas could not replace oil to serve this purpose. Moreover, forest resources are extremely scarce due to arid climatic conditions in Saudi Arabia, and mineral exploitation is also still in the developmental phase. However, the short-run effects of natural gas and forest rents are positive, which corroborates the recent strategic efforts of the Saudi government to diversify the NRR from oil to other resources.

6 Conclusions

NRR could have environmental consequences in the resource-rich Saudi economy. Thus, this research examines the impact of oil, natural gas, mineral, and forest rents on CO_2 emissions in Saudi Arabia using the period from 1970 to 2023. Moreover, the EKC hypothesis is also tested and verified with a turning point of 65,914 SR in the long run. Besides, EKC is verified in the short run with a turning point of 65,912 SR. The estimated turning points are found to be larger than the average per-person GDP. Consequently, the increasing income of Saudi Arabia could have pleasant effects on the environment. OR increases CO_2 emissions. Accordingly, the oil sector has environmental problems in the Kingdom. However, the long-run effects of natural gas, mineral, and forest rents are found to be statistically insignificant. Nevertheless, the short-run effects of all sources of NRR are found to be statistically significant, except for the insignificant effect of mineral rent. Thus, most investigated sources of NRR have environmental problems in the short run.

OR is responsible for increasing CO_2 emissions. The Saudi government has targeted Vision 2030 to diversify from the oil sector to other cleaner sectors. Moreover, some renewable energy projects have also been initiated. Along the same line, the present study suggests that oil refineries and other pollution-oriented industries associated with the oil sector should be taxed to reduce the environmental consequences of OR. In another target of Vision 2030, the government wants to diversify from OR to other NRRs. However, the findings of the research suggest that natural gas and forest rents also pose environmental problems in the short run. Therefore, stricter environmental regulations should be introduced in all types of natural resource production and consumption.

The study faces limitations in terms of data for more proxies for environmental degradation, including biodiversity loss, water contamination, and land degradation. Future research can increase the scope of the research by adding these proxies to analyses. Moreover, the present research could find the Saudi national data, and including region-specific data in future research could support the Saudi regional policy to reduce the environmental effects of NRR.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflict of interest.

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