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Transition to a Low-Carbon Economy in Oil-Exporting Countries: The Role of Macroeconomic Factors

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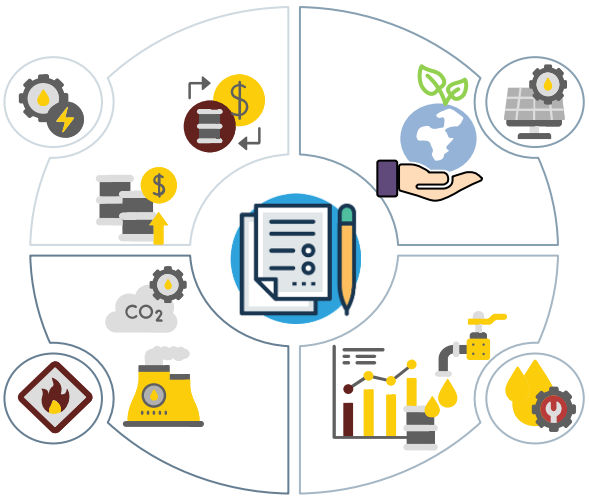
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A B S T R A C T

The increasing consumption of fossil fuels, combined with their non-renewable nature, has intensified carbon dioxide emissions worldwide. This issue is particularly critical in oil-exporting countries due to their strong economic dependence on oil and gas revenues. Accordingly, this study examines the impact of selected economic factors on environmental pollution using panel data from seven oil-exporting countries in the Middle East over the period 1970–2023. The analysis is conducted within a panel econometric framework.The empirical results indicate that gross domestic product [1]has a negative and statistically significant effect on carbon dioxide emissions, suggesting improvements in energy efficiency and a gradual shift in economic structures toward less energy-intensive activities in the studied countries. In contrast, foreign investment and urban population growth exert positive and significant effects on carbon emissions, implying that these factors are mainly concentrated in energy-intensive sectors and heavy industries.Moreover, the findings reveal that renewable energy production is positively associated with carbon dioxide emissions, which may reflect the expansion of clean energy sources alongside increasing total energy consumption rather than a complete substitution of fossil fuels.Overall, the results highlight the importance of policies aimed at enhancing energy efficiency, improving production structures, and strengthening environmental regulations in order to reduce environmental pressure and promote sustainable development in oil-exporting countries.



1. Introduction

In recent years, growing global concerns regarding the environmental impacts of excessive fossil fuel consumption, coupled with the accelerating trend of global warming, have increasingly drawn the attention of policymakers, researchers, and international organizations toward the sustainable and optimal use of energy resources as well as the development and deployment of clean energy technologies [1]. This challenge assumes even greater importance in countries that are rich in fossil fuel resources, particularly oil-exporting nations, where the implementation of renewable energy policies is constrained by specific economic, infrastructural, and institutional factors. These constraints often include heavy dependence on fossil fuel revenues, legacy energy systems designed around conventional energy production, insufficient technological capacity, and regulatory frameworks that are not fully adapted to support the

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integration of renewable energy sources. Iran, as one of the world's largest holders of oil and gas reserves, represents a particularly salient case in this context. The country has historically exhibited high levels of carbon dioxide emissions, reflecting both its energy-intensive industrial structure and its dependence on fossil fuel consumption for economic growth.

A combination of factors has contributed to this persistent challenge, including widespread energy subsidies, low domestic prices for fossil fuels, inefficiencies in energy production and distribution systems, and inadequate regulatory and infrastructural support for cleaner energy alternatives[2]. Despite these obstacles, Iran possesses substantial potential for the development and utilization of renewable energy sources, such as solar, wind, and geothermal energy, due to its favorable geographical conditions and abundant natural resources. Harnessing this potential could play a transformative role in reducing the country's energy intensity and environmental footprint. The significance of this research can be approached from multiple perspectives. From an environmental standpoint, identifying the key drivers of pollutant emissions and exploring strategies to mitigate them can directly contribute to improving air quality and overall environmental conditions. Economically, reducing emissions and energy intensity can lower production costs for industries, enhance the efficiency of resource use, and support broader economic productivity.

From a policy perspective, the study provides an evidence-based foundation for designing and implementing effective strategies that promote renewable energy development while simultaneously reducing dependence on fossil fuels. These considerations give rise to essential research questions: to what extent and in what ways can macroeconomic factors influence reductions in pollutant emissions in oil-exporting countries? Which policy interventions are most effective in accelerating this transition? How does the shift toward a low-carbon economy impact environmental pollution in countries heavily dependent on oil revenues? Previous research has predominantly focused on developed nations or global-scale analyses, often overlooking the unique economic and institutional contexts of oil-exporting countries. As a result, there has been limited investigation into how renewable energy adoption specifically affects emissions in countries such as Iran, where energy intensity is historically high and the structure of the economy is closely linked to fossil fuel production and consumption. To address this gap, the present study utilizes empirical data alongside advanced statistical and econometric methods to examine the influence of key macroeconomic factors including gross domestic product, renewable energy production, foreign investment, population growth, and exchange rate fluctuations on environmental pollution across oil-exporting countries.

In addition to quantifying these relationships, the study seeks to identify actionable policy recommendations to guide sustainable development initiatives. Environmental concerns and the challenges associated with sustainable energy supply have prompted many oil-exporting countries to increasingly adopt renewable energy sources. These energy sources such as solar, wind, and biomass offer a viable alternative to conventional fossil fuels and can play a critical role in reducing carbon dioxide emissions. Their benefits stem not only from their relative environmental cleanliness but also from the integration of modern, highly efficient technologies that reduce energy consumption across industrial, residential, and transportation sectors.

In the case of Iran, abundant solar radiation, wind corridors, and geothermal potential provide a strong foundation for expanding renewable energy, which could substantially lower both carbon dioxide emissions and other environmental pollutants while reducing the country's reliance on fossil fuels [3].Urbanization represents another key factor influencing energy consumption and environmental pollution. Increases in urban populations typically lead to higher energy demand across residential, transportation, and industrial sectors, which can exacerbate emissions and environmental pressures [4]. However, these challenges are not insurmountable. When urban growth is coupled with energy-efficient infrastructure, such as clean public transport systems, energy-saving buildings, and optimized industrial layouts, it is possible to mitigate emissions even as urban populations continue to grow. This emphasizes the importance of integrated urban planning and the implementation of policies that simultaneously support population growth, economic expansion, and environmental sustainability. The relationship between economic growth and environmental pollution is multifaceted and context-dependent. In the early stages of economic development, rising GDP often coincides with increased energy consumption and higher pollutant emissions. Over time, however, as economies mature and adopt energy-efficient technologies and production processes, the intensity of energy use tends to decline, resulting in lower environmental impact. Oil-exporting countries, such as Iran, face additional challenges in this regard due to their energy-intensive industrial base and heavy reliance on fossil fuel revenues, which can complicate efforts to reduce environmental pollutants [5]. Foreign direct investment (FDI) can play a significant role in addressing these challenges. Investment inflows, particularly in the energy sector, facilitate the transfer of advanced technologies and can enhance energy efficiency across various industries. Targeted investment in renewable energy projects, which require both modern technologies and substantial capital expenditures, has the potential to significantly reduce carbon dioxide emissions and other environmental pollutants. In Iran, while economic and political constraints have historically limited the attraction of large-scale foreign investment, improving these conditions could provide a critical pathway for achieving reductions in environmental pollution and supporting the country's transition toward a more sustainable energy system [6].

Timothy and colleagues in a study titled "Economic Factors Affecting Environmental Pollution in Two Nigerian Cities" examined the economic factors affecting pollution in the cities of Iwo and Ibadan using a comparative study and the Bartlett test. The results indicated that people's standard of living and inclination toward a green economy are determining factors of environmental pollution [7]. Wang and Du in a study titled "The Role of Green Finance, Agricultural Development, Geopolitical Risk, and Natural Resources on Environmental Pollution in China" identified the economic factors affecting environmental pollution in China using the quantile autoregressive distributed

lag (QARDL) method. The results showed that factors such as agricultural development, geopolitical risk, and natural resources have a positive and significant relationship with the level of environmental pollutant emissions [8]. Ren and colleagues in a study titled "How Does Green Investment Affect Environmental Pollution? Evidence from China" examined the effect of green investment on environmental pollution using panel data from 30 Chinese provinces from 2006 to 2017 and a spatial Durbin model. The results indicated that environmental pollution is negatively affected by green investment [9]. Sadegh and colleagues in a study titled "The Impact of Financial Development and Economic Growth on Environmental Pollution: Evidence from the G7 Group" examined the effect of financial development, economic growth, and energy efficiency on environmental pollution in G7 countries using panel data and an ARDL model from 1997 to 2021. The results showed a positive and significant relationship between these variables and environmental pollution [10]. Gao and colleagues in a study titled "Green Finance, Environmental Pollution, and High-Quality Economic Development" used panel data and a spatial econometric model to examine the integration of green finance, environmental pollution, and high-quality economic development from 2010 to 2019. The results indicated that green finance plays a significant role in high-quality economic development, but environmental pollution hinders high-quality economic development [11].

2. Method

In this study, inspired by the studies of Corneli and Fanck-Hauser and Gately and Huntington**,** examines the impact of key economic variables including gross domestic product, renewable energy production, foreign investment, population growth, and exchange rate fluctuations on environmental pollution in oil-exporting countries over the period from 1970 to 2023. To ensure a comprehensive and reliable analysis, the necessary statistical data were obtained from authoritative sources, including the World Bank's extensive databases and detailed records from the Energy Institute. This extensive dataset allows for a longitudinal analysis of the interactions between economic growth, energy transitions, demographic changes, and environmental outcomes, providing a solid foundation for understanding the factors influencing pollution in oil-dependent economies and offering valuable insights for policymaking and the formulation of sustainable development strategies. The proposed model framework is as follows:

$$CO_2=f(Production,GDP,Finv,Urbanpop,ER) \quad T=1,2,\ldots,T \tag{1}$$

where CO_2 is the amount of carbon dioxide emissions and a proxy for the amount of environmental pollution, Production is the production of renewable energy, GDP is the gross domestic product, Finv is foreign investment, Urbanpop is the number of urbanized population, and ER is the exchange rate. i is the number of sections, and t is the study period. Considering the nature of the data in this study, the panel data method was used. Initially, descriptive statistics were performed to provide a general picture of the data characteristics and the distribution of variables. In the next step, in order to examine the stationary characteristics of the variables and prevent the occurrence of spurious regression, the Levin-Lee-Chow and Im and Sons stationary tests were applied to the panel data.

After ensuring the stationary conditions, the F-limer test was performed to determine whether the data structure was of a combined or mixed type. Next, the Hausman test was performed to select between fixed effects and random effects models. Based on the results of the Hausman test, the random effects model was selected and estimated as the appropriate model. Finally, in order to evaluate the accuracy and validity of the estimated results, a set of diagnostic

tests including variance heterogeneity and autocorrelation were performed to ensure the robustness and reliability of the model.

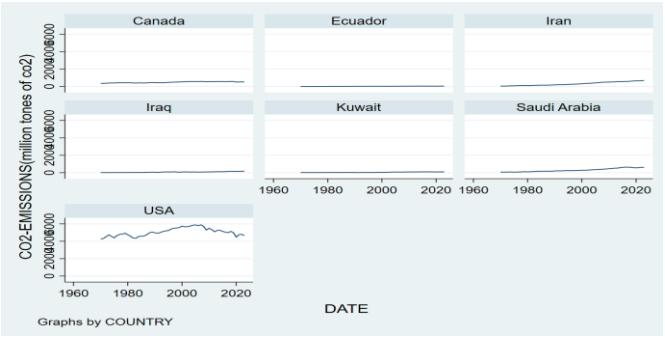


Figure 1. Carbon dioxide emissions of oil-producing countries graph in the years 1973-2023.
Source:research findings

3. Results and Discussion

First, the descriptive statistics of the model variables and an analysis of the data characteristics are presented in Table 1. Descriptive statistics show that environmental pollution is on average low in the countries studied, but there are significant differences in energy consumption patterns and renewable energy use among countries. Also, fluctuations in foreign investment and differences in urbanization levels indicate structural heterogeneity of economies during the study period.

Table 1. Descriptive statistics of variables.

Variable	Mean	Standard Error	Minimum	Maximum
Renewable Energy Production	58.0072	58.0072	58.0072	58.0072
Gross Domestic Production	1.92105	1.92105	1.92105	1.92105
Foreign Investment	8558180.0	1.5449	-8.218787	9.1710
Urban Population	73.2227	14.3271	39.278	100
Exchange rate	30.25	027500.0	1.00	42000

Source: Research findings.

3.1. Results of Levin–Lin–Chu (LLC) and Im & Pesaran Unit Root Test

To ensure the accuracy and robustness of the econometric analysis, the stationarity of all variables in the panel dataset was tested using the Levin–Lin–Chu (LLC) and Im–Pesaran–Shin (IPS) unit root tests. The results indicated that some variables were non-stationary at their level, containing a unit root, which could potentially bias the regression estimates if left unaddressed. However, after applying first-order differencing, all variables became statistically stationary, confirming the absence of unit roots. Achieving stationarity allows the analysis to meaningfully examine both short-term and long-term dynamics without the risk of misleading results arising from non-stationary data (Table 2).

Table 2. Results of Levin–Lin–Chu and Im & Pesaran test to examine the stationarity of the variables in the research model.

Variable	Levin-Lee-Chow Test		Im and Pesaran Test	
Renewable Energy Production	level	First-class distinction	level	First-class distinction
Gross Domestic Production	1.0000	0.99995	0.2365	0.0000
Foreign Investment	-2.011	0.0000	-1.970	0.0000
Urban Population	0.9999	0.0000	1.0000	0.0000
Exchange rate	0.0005	0.0000	0.0000	0.0000

**Indicates significance at the 5% significance level. Source: Research findings.

Then, the results of the Chow test in Table 3 show that at the 5% error level, the data are of mixed type. Also, the F-statistic and Chi-square are significant with a probability value of 0.0000.Therefore, it is necessary to determine the fixed or random effects method. To detect and identify the correct method of estimating the model, the Hausman test was used. Table 4 shows the results of the Hausman test.

Table 3. F-test to detect the fixed effects model or the same width from the origin.

Statistical effects	Test Statistic	Prob.
Cross-section F	717.2020	0.0000 **
Cross-section Chi-square	958.2864	0.0000 **

**Indicates significance at the 5% significance level. Source: Research findings.

Table 4. Results of the Hausman test for choosing a fixed or random effects model.

Prob.	Test Statistic	Statistical Effects
0.3289	4.62	Xi^2

Source: Research findings.

According to the Hausman test, the value of the chi-square for cross-sectional fixed effects is not in the critical region, so the null hypothesis that random effects are appropriate can be accepted. Therefore, at a confidence level of 95%, the random effects model is approved. Finally, the estimation results based on the random effects model are presented in Table 5.

Table 5. Experimental results of factors affecting environmental pollution.

Variable	Coefficient	Test Statistic	Prob.
Renewable Energy Production	0.000102	9.393605	0.0000**
Gross Domestic Production	-0.023332	-7.636184	0.0000**
Foreign Investment	0.000880	1.087866	0.02744**
Urban Population	0.000458	5.335659	0.0000**
Exchange rate	0.002588	4.2151	0.0058**
Constant	0.079899	6.283941	0.0000**
Test statistic		57.38235	
Prob.		0.0000**	

**Significance is indicated at the 5% significance level. Source: Research findings. Source: Research findings.

3.2. Estimation of the Environmental Pollution Pattern of Oil Exporting Countries

This estimation provides a comprehensive view of the factors influencing environmental pollution in oil-exporting countries over the study period. Moreover, the random effects estimation offers insights into the long-term patterns of environmental pollution in these countries, revealing systematic trends that are not observable in simple cross-sectional analyses.

Based on the results presented in the above tables, the estimated coefficient of renewable energy production is 0.000102, which is statistically significant at the conventional levels. This positive coefficient indicates that a one-unit increase in renewable energy production leads, on average, to an increase of 0.000102 units in environmental pollution. The statistical significance of this coefficient suggests the existence of a stable and reliable relationship between these two variables over the period under study. Although the expansion of renewable energy is generally expected to reduce environmental pollution, this result may reflect the fact that, in the countries examined, increases in renewable energy production have occurred simultaneously with rising total energy consumption and the expansion of economic activities. In other words, renewable energy development has not fully substituted for fossil fuels but has instead contributed to an increase in overall energy demand alongside them. This finding may indicate that the energy transition in these countries is still at an early stage and requires further technological improvements and enhancements in energy efficiency.On the other hand, the coefficient of gross domestic product is estimated to be negative and equal to −0.023332, and it is also statistically significant. This result implies that a one-unit increase in gross domestic product leads, on average, to a 0.023332-unit reduction in environmental pollution. The negative and significant coefficient of gross domestic product indicates that economic growth in the countries under study has been associated with a decline in pollution intensity. This finding may support the hypothesis of "growth accompanied by environmental improvement," according to which economic development encourages the adoption of cleaner technologies, improvements in energy efficiency, and a structural shift toward less pollution-intensive production activities. Therefore, economic growth in these countries does not necessarily imply increased environmental degradation and may instead play a mitigating role in environmental pollution.

Furthermore, the urban population variable, with a coefficient of 0.000458 and a probability value of 0.0000, exhibits a positive and highly significant effect on environmental pollution. This result indicates that increased urbanization is directly associated with higher levels of environmental pollution. From a statistical perspective, the extremely low probability value reflects a high degree of confidence in the estimated relationship. Economically, this finding suggests that population concentration in urban areas typically leads to higher energy consumption, expanded transportation networks, increased industrial and service activities, and, consequently, greater environmental pressure. In addition, rapid urban growth without adequate planning may result in inefficient energy use and higher pollutant emissions. Thus, urbanization plays a crucial role in explaining variations in environmental pollution across the countries examined.foreign investment and the exchange rate enter the model with positive and statistically significant coefficients of 0.00088 and 0.002588, respectively. The positive coefficient of foreign investment indicates that increased inflows of foreign capital are associated with higher levels of environmental pollution. This result may suggest that foreign investment in the countries under study has been largely directed toward energy-intensive sectors, heavy industries, and activities with high pollution intensity. From a statistical standpoint, the significance of this coefficient confirms that foreign investment is an important determinant of environmental pollution dynamics.Similarly, the positive and significant effect of the exchange rate suggests that exchange rate increases or fluctuations may intensify environmental pollution through higher costs of importing clean technologies, incentives for exporting energy-intensive goods, or the expansion of pollution-intensive production activities. Accordingly, the exchange rate, as a key macroeconomic variable, plays a notable role in shaping environmental

pollution dynamics in the countries considered. Overall, the statistical results of this model demonstrate that environmental pollution is simultaneously influenced by economic, demographic, and energy-related factors, with each variable exerting a statistically significant and economically interpretable effect. These findings underscore the importance of designing integrated economic, energy, and urban policies to effectively control and reduce environmental pollution in oil-exporting countries.

4. Conclusions

The results of modeling and data analysis show that different variables play an important role in determining the intensity of energy consumption in oil-exporting countries. The findings of this study show that gross domestic product has a very strong and negative effect on environmental pollution. This findinkg indicates that with economic growth, energy consumption decreases relatively. This decrease can be due to improved energy efficiency, the use of more advanced technologies, and a change in the economic structure towards less energy-intensive activities. This shows that countries whose economies have developed can reduce energy consumption by improving the production structure and increasing productivity. Also, foreign direct investment has had a positive effect on energy consumption. This finding indicates that the inflow of foreign capital in the countries under study is likely to be concentrated in energy-intensive sectors and heavy industries. This may have led to an increase in environmental pollution in the long run. This finding could indicate the need for policies that direct foreign investment towards low-energy and sustainable sectors. In the case of urban population, a positive and significant coefficient was observed. This indicates that increased urbanization has led to increased environmental pollution. The reason for this could be that energy consumption is more concentrated and wasteful in urban areas. This finding shows that urbanization without proper planning can lead to increased pressure on energy resources. Finally, renewable energy production also had a positive effect on the level of environmental pollution. This finding is logical and expected, because increasing renewable energy production means increasing overall energy consumption. This could indicate that the countries under study are developing sustainable energy sources. In general, the model results confirm that the level of pollution in oil-exporting countries is significantly and long-term affected by variables such as gross domestic product , renewable energy production, urban population, foreign investment, and exchange rates. Based on the research findings, it is suggested that energy policymakers in oil-rich countries focus on increasing energy efficiency and improving the production structure so that economic growth is accompanied by a reduction in environmental pollution. Also, it is necessary to direct foreign direct investment towards low-energy, technological, and sustainable sectors to prevent its concentration in energy-intensive industries.

On the other hand, considering the positive effect of urbanization on pollution intensity, it is necessary to implement sustainable urban development policies and improve energy efficiency in urban sectors. Finally, the development of renewable energies should be carried out simultaneously with the promotion of technology and energy efficiency so as not to lead to increased pollution. Also, the present study has not been able to include some institutional, technological, and policy factors such as the quality of energy governance or the level of technological progress in the model. In addition, the use of big data may not fully reflect sectoral differences in pollutants, which could pave the way for future research with sectoral data or dynamic methods.

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