Article history:
Received 24 April 2025
Revised 28 May 2025
Accepted 11 June 2025
Published online 01 July 2025

Journal of Resource Management and Decision Engineering

Volume 4, Issue 3, pp 1-10

The Effect of Oil Price Fluctuations on Environmental Pollution in Iran Based on the New GAS Model

Mahdi. Pendar[1*], Elham. Vafaei[2], Azhin. Javaheri[3]

[1] Associate Professor, Department of Agricultural Economics, Faculty of Economics and Agricultural Development, University of Tehran, Karaj, Iran
[2] Assistant Professor, Development and Foresight Research Center, Planning and Budget Organization, Tehran, Iran
[3] Master Student, Department of Agricultural Economics, Faculty of Economics and Agricultural Development, University of Tehran, Karaj, Iran

*** Corresponding author email address**: mpendar@ut.ac.ir

Article Info

Article type:
Original Research

How to cite this article:
Pendar, M., Vafaei, E., & Javaheri, A. (2025). The Effect of Oil Price Fluctuations on Environmental Pollution in Iran Based on the New GAS Model. *Journal of Resource Management and Decision Engineering*, *4*(3), 1-10.
https://doi.org/10.61838/kman.jrmde.4.3.2

ABSTRACT

Today, air pollution caused by emitting pollutants is one of the most serious concerns in the world. CO2 gas emission is considered as one of the most significant and effective pollutants. In addition, the consumption and production of fossil fuels such as oil is one of the factors affecting the over-emission of this kind of gas. Due to the significance of this subject, the present study investigated the effect of oil price fluctuations on the amount of CO2 produced in Iran, as well as the degree of trade openness and Kuznets theory in relation to economic growth and emission of pollutants during 1970-2020. The GAS method was used to estimate the oil price fluctuations and the ARDL method was applied for evaluating the short-term and long-term effects. The results of this study indicated that oil price fluctuations and the degree of trade openness play a negative effect on CO2 emission. In this study, Kuznets' theory was confirmed in relation to economic growth and pollutant emission. In other words, the GDP development can have a negative relationship with CO2 emission after the initial stages. However, such effect is much lower than its positive effect on pollution in the initial stages of development.

Keywords: *GAS model, CO2 emission and Kuznets' theory*

1. Introduction

Environmental degradation caused by anthropogenic activities has emerged as one of the most significant global concerns in recent decades. A critical dimension of this issue is air pollution, particularly the emission of carbon dioxide (CO_2), which is widely acknowledged as a primary contributor to climate change and global warming. Fossil fuel combustion, especially petroleum products, remains the leading source of CO_2 emissions, thereby intertwining environmental quality with energy consumption and economic activity (Erdogan, 2014). In developing economies such as Iran, which are heavily reliant on oil revenues, this dynamic is further complicated by oil price volatility and trade openness, raising important questions about the environmental implications of macroeconomic and energy policy decisions.

The interplay between energy use, economic growth, and environmental sustainability is encapsulated in the Environmental Kuznets Curve (EKC) hypothesis. This theory posits an inverted U-shaped relationship between economic development and environmental degradation, suggesting that pollution intensifies at the early stages of economic growth but eventually declines as income rises and cleaner technologies are adopted (FaikBilgili et al., 2016). Iran, as an oil-dependent economy experiencing rapid urbanization and industrialization, presents a compelling case to examine the empirical validity of the EKC hypothesis alongside the effects of oil price fluctuations and trade openness on CO_2 emissions.

The significance of CO_2 emissions extends beyond national boundaries, given their transboundary environmental consequences. As highlighted by (Pajooyan & Khoshnevis, 2012), environmental pollution not only impairs ecological systems but also adversely affects the Human Development Index (HDI), particularly in the context of developing and oil-exporting countries. The Iranian economy, marked by extensive oil production and trade, is subject to the external shocks of oil price volatility, which can directly and indirectly influence domestic emissions. According to (Cashin et al., 2014), oil price shocks can impact environmental quality through both production-side effects—such as changes in oil output and investment in environmental technologies—and consumption-side effects involving substitution between clean and fossil fuels.

Understanding the environmental consequences of oil price dynamics is further complicated by the role of trade openness. The degree of openness, often measured by the ratio of trade to GDP, can facilitate the import of clean technologies or exacerbate pollution through increased production and energy consumption. As shown by (Tayibi et al., 2018), the liberalization of trade policies in both oil-exporting and importing countries can influence environmental outcomes in divergent ways. While some countries benefit from the “pollution halo” effect due to technology transfer, others suffer from the “pollution haven” phenomenon, where lax environmental regulations attract polluting industries.

The relationship between trade openness and environmental degradation in Iran has also been studied extensively. For instance, (Tagvai & Hajian, 2014) demonstrated that increased openness could lead to higher CO_2 emissions in the absence of environmental regulations. Similarly, (Kohensal & Bahraminaseb, 2018) emphasized that the nexus between energy consumption, economic growth, and pollution is influenced by the policy context in which trade and investment are managed. These findings underscore the need for comprehensive models that can isolate the effects of oil price volatility, economic activity, and trade openness on emissions.

While conventional econometric models have provided valuable insights into these relationships, recent advancements in volatility modeling have enabled more precise estimations. The Generalized Autoregressive Score (GAS) model offers a flexible framework for capturing the time-varying volatility of variables such as oil prices, especially when standard assumptions of normality and stationarity are violated (Chen & Xu, 2019). This model outperforms traditional GARCH-type models by incorporating score-driven dynamics that are robust to outliers and suitable for high-frequency financial and environmental data.

Empirical evidence from various contexts supports the complexity of these relationships. For example, (Mohamued et al., 2021) found that oil price volatility significantly affects greenhouse gas (GHG) emissions in both oil-importing and oil-exporting countries, with the impact mediated by R&D spending and sustainability innovations. Similarly, (Sarker et al., 2023) emphasized the asymmetric effects of geopolitical risks and climate policy uncertainties on clean energy prices, reinforcing the argument that macroeconomic volatility has far-reaching implications for environmental quality.

In the context of emerging economies, the role of renewable and non-renewable energy consumption is particularly relevant. In India, (Malayaranjan & Jayantee, 2020) observed that renewable energy consumption had a mixed effect on CO_2 emissions, while non-renewable energy sources such as coal and oil consistently worsened air quality. These findings resonate with the Iranian context, where fossil fuel dependence dominates the energy mix, and environmental externalities are pronounced.

Air pollution in Iran is not merely an abstract concept; it has tangible consequences for public health and economic productivity. According to (Ghorani-Azam et al., 2016), air pollution in Iran significantly contributes to respiratory and cardiovascular diseases, imposing heavy costs on the healthcare system and reducing quality of life. This burden is particularly severe in industrial regions such as Ahvaz, where pollution sources include oil refineries, petrochemical plants, and vehicular emissions (Velayatzadeh, 2020).

The spatial and temporal patterns of air pollution also reflect the influence of macroeconomic variables. For example, (Yongyou et al., 2020) employed wavelet analysis to reveal how international oil price fluctuations correlate with PM2.5 concentrations in Chinese cities, highlighting the lagged and dynamic nature of this relationship. In a similar vein, (Xu et al., 2023) examined how foreign direct investment (FDI), renewable energy, and education jointly influence CO_2 emissions in E-7 nations, arguing that institutional and human capital factors play a critical mediating role.

Iran's environmental challenges are further exacerbated by its reliance on oil exports and the volatility of global oil markets. As pointed out by (Bilali et al., 2012), fluctuations in oil prices can have both direct and indirect effects on emission levels, depending on how revenues are allocated and whether cleaner technologies are adopted. In many cases, the lack of targeted investment in green infrastructure has meant that oil windfalls are not effectively leveraged to reduce pollution (Madah & Abdicherlo, 2020).

Using the GAS model to estimate oil price fluctuations and the Autoregressive Distributed Lag (ARDL) method to analyze long- and short-term relationships, this study fills a critical gap in the literature. It simultaneously considers the roles of gross domestic product (GDP), trade openness, and oil price volatility in determining CO_2 emissions in Iran from 1970 to 2020. By doing so, it provides a nuanced understanding of how macroeconomic shocks and structural characteristics shape environmental outcomes.

2. Methods and Materials

In this study, the short-term and long-term effects of oil price fluctuations, the degree of trade openness, and the gross domestic product and the square root of the gross domestic product on CO2 emission were evaluated using the ARDL model during 1970-2020 and the general form of the equation is as follows:

$$L(Co_2) = \alpha + \beta_1 L(oil) + \beta_2 L(dgree) + \beta_3 L(\mathrm{GDP}^2) + \beta_4 L(GDP) + Dmy + u_t$$

where LCo_2 represents the logarithm of CO2 emission, L(oil) indicates the logarithm of oil price fluctuations, L(dgree) shows the logarithm of the degree of trade openness, L(GDP) is the logarithm of gross domestic product, and $L(GDP^2)$ implies the logarithm of the square power of production gross domestic product. A dummy variable (dmy) was used to fix the structural failure due to the existence of a structural failure in Iran's oil price fluctuation diagram. The degree of trade openness was obtained from the following equation:

$$\mathrm{Dgree} = \frac{IM + EX}{GDP}$$

where IM, EX, and GDP represent the amount of imports, exports, and gross domestic product of the agricultural sector, respectively.

In this study, GAS method was used with the help of OXmetrics7 software to estimate oil price fluctuations. In addition, the estimation of the final ADRL model was conducted in EViews7 software.

2.1. GAS generalized autoregressive score model

In classical models, the GARCH method which is rooted in the ARCH method presented by Engel (1982), is used for estimating uncertainty and volatility. The sensitivity to the outliers is one of the weaknesses of the ARCH method. In addition, one of the practical properties of the GAS framework is its use in defining time-varying parameter models in abundant types of multivariate time series settings.

This model is in the category of observation-based models, including the well-known models such as the GARCH method in which the conditional distribution of the ARCH and GARCH methods is used. Assume the GAS method (p,q) where rt represents a k-dimensional random vector at time t with conditional distribution:

$$Y_t | Y_{1:\,t-1} \approx p(Y_t\,;\ \theta_t)$$

where $Y_{1:\,t-1} \equiv (Y_1^T, \dots, Y_{t-1}^T)^T$ and Y_{t-1} values represent the sigma algebra created by the time series to time t, θ_t shows the vector of time series parameters with density function p(.) which depends on Y_{t-1}.

The time series parameters θ_t are created by the conditional distribution scalable score function and its first-order function is as follows:

$$\theta_{t+1} = k + As_t + B\theta_t$$

where k, A, B show the matrix of coefficients and the scaling score function s_t as follows:

$$s_t = s_t \nabla_t + B\theta_t$$

$$\nabla_t = \frac{\delta lnp(r_t;\theta_t)}{\delta\theta_t}$$

$$s_t = ŋ_t(\theta_t)^{-\gamma}$$

$$ŋ_t(\theta_t) = E_{t-1}[\nabla_t \nabla_t^T] = -E_{t-1}[\frac{\delta^2 lnp\ (r_t;\theta_t)}{\delta\theta_t \delta\theta_t^T}]$$

In the above-mentioned equations, γ represents a number from the set {0, 1.2, and 1}. The value of s_t changes the time series parameters from θ_t to θ_{t+1}, which is similar to the well-known Newton-Raphson algorithm.

2.2. ARDL method

The ARDL method is appropriate for evaluating the dynamic equilibrium behavior of economic variables in the short and long terms since these methods can examine the effects of dependent variable lags on the dependent variable, the effects of influencing independent variables, and their lags on the dependent variable.

In this study, the ARDL method was applied to estimate the short-term and long-term effects of oil price fluctuations and energy consumption and the model can be generally defined as follows:

$$\alpha(L,P)Y_t = \sum_{i=1}^{k} \beta_i\ (L,q_i)X_{it} + \delta W_t + u_t$$

where:

$$\alpha(L,P) = 1 - \alpha_1 L - \alpha_2 L^2 - \cdots - \alpha_p L^q$$

$$\beta(L,q_i) = 1 - \beta_{i1} L^2 - \cdots - \beta_{iq} L^q$$

L represents a lag, a vector of deterministic variables such as y-intercept, trend variable, dummy variables, or exogenous variables. P shows the lags used for the dependent and independent variables.

The ARDL method occurs in two stages. In the first stage, the presence of long-term relationship between the studied variables is tested and the dynamic model tends towards long-term equilibrium if the sum of the estimated coefficients related to the dependent variable is smaller than one. As a result, the following hypothesis is essential for the convergence test:

$$H_0: \sum_{i=1}^{p} \alpha_i - 1 \geq 0$$

$$H_1: \sum_{i=1}^{p} \alpha_i - 1 < 0$$

This test is conducted using the t-test and its statistic can be calculated as follows:

$$T = \frac{\sum_{i=1}^{p} \acute{\alpha}_i - 1}{\sum_{i=1}^{p} \delta\acute{\alpha}_i}$$

If the critical quantity provided by Banerjee, Dolado and Mestre is less than the quantity of the above-mentioned calculated t statistic at the desired confidence level, the hypothesis H0 is rejected and there is a long-term equilibrium relationship between the variables of the model.

At first, oil price fluctuation values were calculated using the GAS method and OXmetrics software, and then the obtained fluctuation values were regarded as an independent variable and its stability and other independent variables were investigated. After evaluating the degree of stationarity, as it was confirmed that the degree of stationarity for the variables was zero and one, the ARDL method was applied to estimate the long-term and short-term relationships.

3. Findings and Results

3.1. Estimation of oil price fluctuations

Oil price fluctuations were modeled using the GAS method, the results of which are shown in Table 1:

Table 1

Descriptive results of oil price variable

Variable	Kurt	skw	jarquebera	Std.dev	mean	arch
L(Oil)	25.7	1.12	3.08 (0.000)	4.5	41.44	1.01 (0.000)

Based on Table 1, the residual term of the oil price variable is abnormal and has ARCH effects since the GAS method has no limitations in estimating the fluctuations of non-normal variables. Since the presence of ARCH effects has been confirmed, the oil price fluctuations variable is estimated. Here is the study of the stationary related to the variables.

3.2. The stationarity of variables

False regression and statistical inference are wrong when the studied variables are non-stationary. In addition, it is possible that the R2 level is sometimes high despite the non-stationary of the variables, in which case the results can be misleading. Therefore, the stationary of the variables has been studied using the augmented Dicky Fuller method to prevent the misleading:

Table 2

The results of Augmented Dickey Fuller Static Test

Variables	In level	Prob	First diffrence	prob
L(CO2)	-0.98	0.74	-6.26	0.000
L(Oil)	-7.46	0.000	-	-
L(dgree)	-1.79	0.37	-4.99	0.000
L(GDP)	0.3	0.95	-5.96	0.000
L(GDP^2)	0.02	0.95	-5.93	0.000

Based on the results in Table 2, the degree of trade openness, CO2 emission, gross domestic product, and square root of gross domestic product are stationary with one-time differentiation and the fluctuation variable of Iran's oil price is at a stationary level. Since the degree of stationarity related to the variables is between 0 and 1, the ARDL method was used to estimate the long-term relationship. In the following, band test was applied for checking the existence of long-term relationship.

3.3. Bound test

Bound test or F test is a test which examines the presence of a long-term relationship between the independent and dependent variables. The obtained results of the long-term relationship between the variables are shown in Table 3:

Table 3

The results of F-Bounds test to estimate the long-rum relationship

F-statistic	signif	1 %	2.5%	5%	10%
8.02	I(0)	3.29	2.88	2.56	2.2
	I(1)	4.37	3.87	3.49	3.09

The presence of a long-term relationship is confirmed since the calculated F statistic, which is equal to 8.02, is more than the upper limit values.

3.4. Estimating ARDL dynamic model

Table 4 indicates the results obtained from the ARDL dynamic model estimation:

Table 4

The results of dynamic ARDL (4,4,3,4,4)

Variables	coefficient	t-statistic	Prob
L(CO2(-1))	-0.68	-3.47	0.004
L(CO2(-2))	-0.24	-1.31	0.21
L(CO2(-3))	0.63	3.27	0.006
L(CO2(-4))	0.27	3.15	0.008
L((GDP^2)	-1.02	-11.1	0.000
L(($GDP^2(-1)$)	0.06	0.44	0.66
L(($GDP^2(-2)$)	-0.18	-1.38	0.19
L(($GDP^2(-3)$)	0.36	2.93	0.01
L(($GDP^2(-4)$)	-0.003	-1.89	0.08
L(GDP)	13.71	11.15	0.000
L(GDP(-1))	-0.79	-0.43	0.66
L(GDP(-2))	2.69	1.49	0.16
L(GDP(-3))	-4.96	-2.95	0.01
L(OIL)	-0.001	-3.74	0.002
L(OIL(-1))	-0.016	-4.93	0.000
L(OIL(-2))	-0.02	-5.3	0.000
L(OIL(-3))	-0.04	-4.79	0.000
L(OIL(-4))	-0.04	-3.64	0.003
L(dgree)	-0.13	-4.39	0.000
L(dgree (-1))	0.14	3.62	0.003
L(dgree (-2))	-0.05	-1.41	0.18
L(dgree (-3))	-0.16	-3.68	0.003
L(dgree (-4))	-0.19	-5.19	0.000
Dmy	-0.007	-0.87	0.39
C	34.89	-3.71	0.002
R^2= 0.99	$\bar{R}^2$=0.99	F=695.55 (0.000)	

Based on the results, the value of R^2 statistic indicating the change of dependent variable compared to independent variables is 0.99.

3.5. Estimating long-term relationship

When the long-term relationship between the independent and dependent variables was confirmed, the long-term ARDL model was estimated to evaluate the long-term relationship between the variables, the results of which are presented in Table 5:

Table 5

The results of long-run ARDL model estimation

Variables	coefficient	Std.error	t-statistic	Prob
L((GDP^2)	-0.76	0.02	-26.49	0.000
L(GDP)	10.42	0.39	26.61	0.000
L(OIL)	-0.12	0.043	-2.95	0.01
L(Dgree)	-0.063	0.03	-1.98	0.07
C	-34.17	1.25	-27.27	0.000

As mentioned earlier, the square root of the GDP was entered into the model as an independent variable to investigate the Kuznets theory regarding the relationship between pollution and GD. Based on the obtained results, the Kuznets theory regarding pollution was confirmed. Kuznets believed that pollution increases by increasing GDP, and then the relationship reverses after a while and pollution decreases by increasing GDP. Based on the results, the degree of trade openness and oil price fluctuation has a negative effect on the emission of pollution. In other words, CO2 emissions increase by 0.12% with each unit decrease in oil price fluctuation.

3.6. Estimating error correction model ECM

The error correction model establishes a relationship between the short-term and long-term values of the variables. In addition, the ECM coefficient indicates the percentage of the short-term imbalance adjusted to the long-term balance in each period. The results of the long-term error correction model for the effect of oil price fluctuations on CO2 emission are given in Table 6:

Table 6

Estimating ECM

Variables	coefficient	Std.error	t-statistic
D (L(CO2(-1)))	-0.22	0.074	-2.99
D (L(CO2(-2)))	-0.21	0.077	-2.76
D(L(dgree))	-0.05	0.02	-2.55
D(L(GDP))	8.52	0.74	11.46
D (L(GDP2))	-0.62	0.05	-11.45
D (L(OIL))	-0.001	0.001	-0.83
Dmy	-0.02	-0.004	-4.79
ECM(-1)	-0.81	0.1	-7.44
$R^2 = 0.77$	$\bar{R}^2 = 0.81$		

As shown, the error correction model (ECM) is negative and statistically significant at the 1% level. Moreover, the value of ECM coefficient equals -0.81. Based on the stated theories, the coefficient should be between 0 and -1 and accordingly the result is acceptable. In other words, 0.81% of the imbalance of one period is adjusted in the next period. The adjustment speed equals $\frac{1}{0/81} = 1/23$. In other words, it takes approximately 15 months to adjust. Based on the results obtained in this study, Kuznets' theory is confirmed and the gross domestic product reduces air pollution in the long term from a certain point onwards. In addition, the degree of trade openness has a negative effect, which is equal to (-0.063) on CO2 emission. In other words, the amount of CO2 emission decreases (-0.063) with each unit of increase in the degree of trade openness. On the other hand, Iran's oil price fluctuations have an effect of (0.12) on CO2 emission. In fact, CO2 emission decreases by (0.12) with each unit increase in oil price fluctuations.

4. Discussion and Conclusion

The present study investigated the long- and short-term effects of oil price fluctuations, gross domestic product (GDP), and trade openness on CO_2 emissions in Iran during the period 1970–2020, using the Generalized Autoregressive Score (GAS) model and Autoregressive Distributed Lag (ARDL) method. The results indicated that fluctuations in oil prices had a statistically significant negative effect on CO_2 emissions, while GDP had an inverted U-shaped relationship with emissions—confirming the Environmental Kuznets Curve (EKC) hypothesis. Additionally, the degree of trade openness also exhibited a negative relationship with CO_2 emissions, though its significance varied across different model specifications.

One of the most significant findings is that oil price fluctuations negatively impact CO_2 emissions in Iran. In other words, an increase in oil price volatility leads to a decrease in emissions. This supports the notion that heightened oil price uncertainty pushes economies like Iran's—heavily reliant on oil—toward more cautious and possibly less polluting consumption behaviors. These results align with previous studies suggesting that oil price shocks affect environmental quality through both production and consumption channels. Specifically, in oil-exporting nations, higher oil prices often encourage investment in technology and environmental management, whereas in oil-importing countries, they accelerate the transition to cleaner energy sources (Cashin et al., 2014; Mohamued et al., 2021). The result also confirms the theoretical assumptions by (Chen & Xu, 2019), who argued that the dynamics of price volatility influence both real activity and environmental performance due to investor uncertainty and shifts in resource allocation.

This negative relationship between oil price volatility and emissions also reflects the behavior of economic agents in the face of uncertainty. When oil prices fluctuate unpredictably, the private sector may defer energy-intensive investments, and the government might redirect fiscal resources from energy subsidies toward more productive, less carbon-intensive sectors. Furthermore, the adoption of GAS modeling provides empirical robustness to this result, as it overcomes the limitations of GARCH-based approaches, which are often sensitive to outliers (Chen & Xu, 2019; Derpich, 2024).

A second major finding is the confirmation of the Environmental Kuznets Curve (EKC) hypothesis. The empirical model shows that GDP has a positive relationship with CO_2 emissions at initial levels of development but a negative relationship after surpassing a certain threshold. This is indicated by the positive coefficient for GDP and the negative coefficient for the squared term of GDP. Such an inverted U-shaped curve suggests that while industrialization and increased energy consumption initially elevate emissions, economic maturity tends to foster environmental awareness, technological innovation, and regulatory frameworks that ultimately reduce pollution levels. This finding is consistent with (FaikBilgili et al., 2016), who used OECD countries to confirm the EKC hypothesis, and with (Bilali et al., 2012), who validated this relationship in Iran's oil sector. Moreover, (Yang & Lee, 2022) provided a similar argument for China's transition to a low-carbon economy through provincial CO_2 quota allocations, supporting the idea that growth can be decoupled from environmental degradation with the right policy interventions.

It is worth noting that while the EKC was confirmed in this study, its turning point is crucial for policy. If the turning point occurs at a relatively high level of income, the environmental costs accrued before this stage can be substantial. As (Pajooyan & Khoshnevis, 2012) highlighted, environmental degradation adversely affects human development indicators and imposes long-term socio-economic costs. Thus, achieving the EKC turning point sooner should be an explicit policy objective, supported by environmental investments and incentives for green technology.

The third core result pertains to the role of trade openness. The study found that higher degrees of trade openness are associated with lower levels of CO_2 emissions in the long run. This may be due to the diffusion of environmentally friendly technologies and the adoption of international environmental standards through global integration. The finding supports the "pollution halo" hypothesis rather than the "pollution haven" hypothesis. According to (Tayibi et al., 2018), the liberalization of trade openness in oil-exporting and oil-importing countries led to improvements in environmental quality. This is consistent with the work of (Xu et al., 2023), who found that foreign direct investment and trade openness reduced emissions in E-7 nations when complemented by green investments and education. Similarly, (Pata et al., 2023) found that in ASEAN countries, trade openness played a role in mitigating emissions, provided that renewable energy and tourism were leveraged in tandem with FDI.

This outcome also reinforces the importance of trade policy in environmental management. In Iran's context, trade liberalization may enable access to cleaner production technologies and greener inputs, thereby mitigating the pollution intensities associated with economic expansion. The results align with (Tagvai & Hajian, 2014), who demonstrated a positive long-run link between trade openness and environmental degradation in Iran, but emphasized the role of policy in shaping the direction of this relationship. Our findings suggest that Iran might be currently on a trajectory where trade is contributing positively to environmental outcomes, potentially through cleaner imports or technology spillovers.

It is also important to consider that trade openness alone may not guarantee reduced emissions. As noted by (Velayatzadeh, 2020), localized sources of air pollution—particularly in industrial cities like Ahvaz—persist regardless of broader macroeconomic trends. Therefore, the effectiveness of trade openness in reducing emissions likely depends on the composition of trade, regulatory alignment with environmental standards, and the degree to which clean technologies are diffused across sectors.

An integrative perspective that includes oil volatility, trade openness, and GDP offers a more holistic understanding of environmental performance in resource-dependent economies. As (Sarker et al., 2023) argued, asymmetric effects of geopolitical risks and oil shocks must be considered in environmental planning. This resonates with the Iranian context, where sanctions, market shocks, and geopolitical dynamics shape the structure of trade and energy policy. Moreover, (Chan, 2020) showed that macroeconomic policies—particularly those integrating fiscal and environmental goals—can be more effective in reducing emissions than standalone environmental regulations. This supports a comprehensive policy approach where economic planning and environmental governance are tightly integrated.

Despite its methodological rigor and empirical contributions, this study faces several limitations. First, the dataset spans from 1970 to 2020, and while this allows for long-term trend analysis, recent structural shifts in Iran's economy—especially post-2020—are not captured. Second, the analysis focuses primarily on macroeconomic variables and does not account for sectoral differences or regional disparities in emissions, which can be significant in a geographically and industrially diverse country like Iran. Third, while the GAS model provides a sophisticated mechanism to estimate oil price volatility, it does not differentiate between supply-side and demand-side oil shocks, which may have heterogeneous environmental impacts. Finally, the measure of trade openness used in this study is aggregate in nature, without distinguishing between trade in environmentally intensive goods and cleaner technologies.

Future studies could extend this work in several directions. One promising avenue is to employ disaggregated data at the sectoral or regional level to better understand the micro-level impacts of oil price volatility and trade openness on emissions. This would allow policymakers to tailor interventions more precisely. Second, differentiating between types of energy sources—such as renewables, natural gas, and coal—would add granularity to the analysis and help isolate cleaner transitions. Third, incorporating environmental regulation indices or institutional quality measures could clarify the role of governance in moderating the pollution-growth nexus. Additionally, future studies could explore asymmetric effects using nonlinear ARDL or threshold models, especially given that environmental responses to economic shocks are not always linear. Finally, a comparative study across other oil-exporting countries could contextualize Iran's experience and offer cross-national policy lessons.

To leverage the study's findings, policymakers in Iran should prioritize the integration of macroeconomic planning with environmental sustainability goals. This involves mainstreaming environmental impact assessments in trade and fiscal policies and ensuring that oil revenues are strategically invested in green infrastructure. Trade openness should be encouraged selectively by prioritizing partnerships that facilitate clean technology transfers and reduce carbon-intensive imports. Moreover, accelerating the energy transition by reducing fossil fuel subsidies and promoting renewable energy will be essential in achieving the EKC turning point at a lower income level. Capacity building in environmental governance, coupled with public awareness initiatives, can reinforce these efforts and ensure broader societal engagement in sustainability transitions.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

References

Bilali, H., Zamani, A., & Yousefi, A. (2012). The relationship between economic growth and environmental pollution in the oil sector with an emphasis on its price fluctuations (a case study of Iran's economy). *Scientific-Research Quarterly of Planning and Budget*, *3*(18), 49-65. http://jpbud.ir/article-1-1070-en.html

Cashin, P., Mohaddes, K., Raissi, M., & Raissi, M. (2014). The differential effects of oil demand and supply shocks on the global economy. *Energy Economics*, *44*, 113-134. https://doi.org/10.1016/j.eneco.2014.03.014

Chan, Y. T. (2020). Are macroeconomic policies better in curbing air pollution than environmental policies? A DSGE approach with carbon-dependent fiscal and monetary policies. *Energy Policy*, *141*, 111454. https://doi.org/10.1016/j.enpol.2020.111454

Chen, R., & Xu, J. (2019). Forecasting volatility and correlation between oil and gold prices using a novel multivariate GAS model. *Energy Economics*, *78*, 379-391. https://doi.org/10.1016/j.eneco.2018.11.011

Derpich, I. (2024). Pursuing Optimization Using Multimodal Transportation System: A Strategic Approach to Minimizing Costs and CO2 Emissions. *Journal of Marine Science and Engineering*, *12*(6), 976. https://doi.org/10.3390/jmse12060976

Erdogan, A. E. (2014). Bilateral trade and the environment: a general equilibrium model based on good for the environment? *American Economic Review*, *91*(4), 877-908. https://doi.org/10.1257/aer.91.4.877

FaikBilgili, E., Koçak, b., & Ümit, B. (2016). The dynamic impact of renewable energy consumption on CO2 emissions: A revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews*, *54*, 838-845. https://doi.org/10.1016/j.rser.2015.10.080

Ghorani-Azam, A., Riahi-Zanjani, B., & Balali-Mood, M. (2016). Effects of air pollution on human health and practical measures for prevention in Iran. *Journal of Research in Medical Sciences*, *21*(1). https://journals.lww.com/jrms/fulltext/2016/21000/effects_of_air_pollution_on_human_health_and.65.aspx

Kohensal, M. H., & Bahraminaseb, M. (2018). Evaluating the relationship between energy consumption and pollution with economic growth in line with general environmental policies. *Strategic and Macro Policy Quarterly*, *8*(28), 500-525. https://www.jmsp.ir/article_102261_en.html?lang=en

Madah, M., & Abdicherlo, M. (2020). Evaluating the effect of oil on environmental pollution in OPEC member countries based on general policies. *Strategic and Macro Policy Quarterly*, *8*(9), 24-37. https://www.jmsp.ir/mobile/article_102270.html?lang=en

Malayaranjan, S., & Jayantee, S. (2020). Effects of renewable and non-renewable energy consumption on CO2 emissions in India: Empirical evidence from disaggregated data analysis. *Journal of Public Affairs*, e2307. https://doi.org/10.1002/pa.2307

Mohamued, E. A., Ahmed, M., Pypłacz, P., Liczmańska-Kopcewicz, K., & Khan, M. A. (2021). Global Oil Price and Innovation for Sustainability: The Impact of R&D Spending, Oil Price and Oil Price Volatility on GHG Emissions. *Energies*, *14*, 1757. https://doi.org/10.3390/en14061757

Pajooyan, J., & Khoshnevis, M. (2012). Investigating the Effect of Environmental Pollution on Human Development Index in Developed Countries. *Journal of Financial Economics*, *6*(20), 39-67.

Pata, U. K., Dam, M. M., & Kaya, F. (2023). How effective are renewable energy, tourism, trade openness, and foreign direct investment on CO2 emissions? An EKC analysis for ASEAN countries. *Environmental Science and Pollution Research*, *30*(6), 14821-14837. https://doi.org/10.1007/s11356-022-23160-z

Sarker, P. K., Bouri, E., & Marco, C. K. L. (2023). Asymmetric effects of climate policy uncertainty, geopolitical risk, and crude oil prices on clean energy prices. *Environmental Science and Pollution Research*, *30*(6), 15797-15807. https://doi.org/10.1007/s11356-022-23020-w

Tagvai, M., & Hajian, P. (2014). *Investigating the relationship between economic growth, energy consumption, degree of international economic openness and environmental pollution in Iran*

Tayibi, S. K., Aghili, F., & Allahdadian, L. (2018). Liberalizing the degree of openness of the economy, oil shocks and environmental quality: with the application of oil exporting and importing countries. *Environmental Science Quarterly*, *1*(16), 159-172.

Velayatzadeh, M. (2020). Air pollution sources in Ahvaz city from Iran. *Journal of Air Pollution and Health*, *5*(2), 147-152. https://doi.org/10.18502/japh.v5i2.4243

Xu, P., Zhang, J., & Mehmood, U. (2023). How do green Investments, foreign direct investment, and renewable energy impact CO2 emissions? Measuring the role of education in E-7 nations. *Sustainability*, *15*(19), 14052. https://doi.org/10.3390/su151914052

Yang, F., & Lee, H. (2022). An innovative provincial CO2 emission quota allocation scheme for Chinese low-carbon transition. *Technological Forecasting and Social Change*, *182*, 121823. https://doi.org/10.1016/j.techfore.2022.121823

Yongyou, N., Pingchao, C., Tasangyao, Z., & Enci, W. (2020). Impacts of international oil price fluctuations on China's PM2.5 concentrations: a wavelet analysis. *Economic Research-Ekonomska Istraživanja*, *33*(1), 2488-2508. https://doi.org/10.1080/1331677X.2019.1656098