Regional spillover effects of natural resource extraction on ecological footprint in the Middle East

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Abstract

The extraction of oil and gas resources in the Middle East region is a primary source of income and economic growth. These resources have not only failed to drive these countries towards development but have also put pressure on the environment. However, the environmental consequences, particularly the regional and transboundary impacts on the ecological footprint, remain insufficiently examined. Then, this research examines the impact of gas extraction on the ecological footprint in the Middle East over the period 2000 - 2021. The main contribution of this paper lies in revealing the regional and cross-border ecological impacts of gas extraction, which were previously unexplored in the literature. The spatial panel SDM framework allows for robust estimation of these effects. The estimated spatial Rho coefficient indicates that the ecological footprint determinants in a country have spillover effects on neighboring countries' environmental quality. This result highlights the necessity of enforcing intra-regional environmental regulations in the Middle East. In addition, focusing on technical coordination, the support of neutral third parties, and flexible, non-binding arrangements can be especially effective in the geopolitically fragmented Middle East. Moreover, our results show that local natural gas extraction significantly increase environmental degradations in the home country. Therefore, implementing new technologies for energy extraction to reduce the emissions intensity of oil and gas operations, enforcing stricter environmental protection regulations, and adopting policies to reduce the economy's dependence on natural resources can decrease their ever-increasing reliance on natural resources, ultimately improving environmental quality. Additionally, the hypothesis of Environmental Kuznets' Curve is rejected in the Middle East region, denoting that environmental preservation policies are not accompanied by an economic acceleration process in the Middle East. They still prioritize economic growth issues over environmental concerns.

Keywords: Ecological footprint, spatial econometrics, Gas extraction, Middle East

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1. Introduction

The Middle East hosts some of the world's leading oil and gas producers, including five of the top ten major oil-exporting nations. In 2022, out of 3998 billion cubic meters of gas production worldwide, 701 billion cubic meters were from the Middle East, representing 17.5% of the world's total gas production, a 32% increase compared to 2021 (IEA 2022). Among Middle Eastern countries, in 2022, Iran produced the highest volume of natural gas at 251 billion cubic meters, followed by Qatar and Saudi Arabia. In addition, the Middle East region holds the most reserves of natural resources, particularly oil and gas, with their economies heavily reliant on energy exports. For example, over

98% of Iraq's GDP depends on oil exports, while in Qatar, more than 70% of government revenue, over 60% of the GDP, and almost 85% of export revenues come from oil and gas.

In one hand, the growing trend of the global economy and the increase in energy demand has posed significant challenges for the Middle East in fulfilling the world's growing energy demand (Energy Institute, 2025). It has led to significant expansion in oil and gas industries in the mentioned countries in recent decades (especially in Qatar, Oman, United Arab Emirates, Saudi Arabia, Iran, and even Iraq). On the other hand, the development of these industries has led to environmental degradations that threaten the health of living organisms and the ecosystem (Razzaghi, Fotros, 2025). Operations in the oil and gas sector can lead to contamination of the land, atmosphere, and climate through processes such as drilling, hydraulic fracturing, and wastewater disposal. In this context, Ben Salha & Zamim (2023) argued that in Saudi Arabia, a 10% increase in gas extraction reduces environmental quality by 4 percent. Razzaghi and Fotros (2024) also indicate that a 1% increase in gas extraction in neighboring countries contributes to a 4% rise in the fisheries footprint within the Middle East region. Therefore, considering the adverse environmental effects of energy extraction is an important issue, especially for the resource-reach region of the Middle East.

Environmental degradation is one of the most critical challenges in sustainable development issues. Human activities affect adversely the environment quality in many ways. Constructions on sea beds and in forest areas, building roads, overconsuming of fossil fuels, resource extraction, urbanization, overpopulation, and deforestation are examples of destructive actions of humans on the planet. These operations result in significant environmental impacts, including pollution of air and water, climate alteration, destruction of habitats, and reduction of biodiversity. For example, Nadim et al. (2008) showed that coastal developments in the Persian Gulf led to stress on marine life and reshape shoreline habitats. In addition, an environmental group report indicates that the construction of the Botaş Saros FSRU Terminal along the northeastern shore of the Gulf of Saros resulted in the cutting of more than 10,000 trees for pipeline routes (Nadim et al., 2008). Then, on the one hand, along with the rapid economic growth of societies, the global demand for fossil fuels, such as coal, oil, and natural gas increases sharply. On the other hand, the extraction of the non-renewable resources gives rise to considerable environmental concerns about the atmosphere, aquatic animals, terrestrial fauna, and the biosphere in general, especially when this process is going on for a long time. Several environmental indicators measure the depth of environmental degradation caused by human activities. Ecological footprint is an integrated indicator used to assess and indicates ecological sustainability (Zafar 2019). In contrast to other indices as the greenhouse gas emission indicator, the ecological footprint index comprehensively measures a set of pressures on cropland, grazing land, forest, fishing ground, build-up land and the air (Uddin et al. 2017, Wilson & Anielski 2004). According to the Living Planet Report in 2022, the worldwide ecological footprint was more than 20 billion global hectares. The average footprint per person was 2.58 global hectares, while the biological capacity was 1.51 global hectares per capita; meaning that humans consume almost 50% more than reserves. For sustainable exploitation, natural resources must be used at a rate as fast as they are replenished by nature (WWF 2022). The ecological deficit index reflects the degree to which humanity's consumption of natural resources surpasses the biological capacity of the region that supports it. According to Ecological Footprint Data (2024), the ecological deficit in the Middle East region has increased in the last decade.

The primary objective of this study is to investigate the environmental degradation effects associated with natural gas extraction in 12 selected Middle Eastern countries[1] during the period 2000–2021. As highlighted by numerous researchers[2], the environmental damages caused by gas extraction are not confined to the extraction sites but extend across the entire region. In the context of the Middle East, countries in the region are highly interconnected through shared ecosystems, cross-border energy infrastructure, trade in energy-intensive goods, and transboundary air and water pollution. Therefore, ignoring spatial spillover effects may lead to biased and incomplete conclusions regarding the environmental consequences of natural gas**.** Therefore, the key contribution of this study is to examine the spillover effects of environmental degradation in the Middle East resulting from gas extraction activities. In addition, considering natural gas extraction as one of the most critical factors in affecting the ecological footprint in the Middle

[1] These countries include: Saudia Arabia, Qatar, Iraq, Iran, Kuwait, Oman, Türkiye, Jordan, Yemen, Bahrain, Syria, and United Arab Emirates.

[2] See for example: Karimi et al. (2022), Hjorth et al. (2021)

East area, for the first time, is another distinction of this study. The rest of the article is compiled as follows: After the introduction in Section 1, Section 2 provides the theoretical framework and literature review. Sections 3 and 4 present the research methodology and empirical results, respectively. Finally, Section 5 offers the concluding remarks.

2. Literature Review

Ecological footprint is a comprehensive indicator that indicates the extent of environmental degradation (in terms of: air, water, and soil) caused by human activities. It shows the biological capacity of the environment in the regeneration of all its natural resources that have been consumed and absorb the wastes generated by people. Therefore, excessive use and extraction of natural resources will weaken the environment's ability to regenerate and ecological footprint exceeds biological capacity an ecological deficit will arise (Khezri et al. 2023a). According to a bulk of empirical studies, lots of economic variables affect ecological footprint that leads to ecological deficit, like: extraction of natural resources, GDP growth, energy consumption, renewable energy consumption, urbanization, income inequality, foreign direct investment, etc. The channels through which these factors affect ecological footprint are reviewed below.

2.1. The ecological footprint of energy extraction

Oil and gas resources bring abundant effortless income to countries. These revenues vast governments' financial capacity and make their budgetary programs feasible. Therefore, countries have more tendency to exceedingly extract natural resources. However, the existence of a positive correlation between natural resource extraction and the emission of various pollutants is noticeable[3]. According to World Energy Outlook, approximately 15% of world greenhouse gas pollution originates from oil and gas operations and consuming gas and oil results in another 40% of emissions (IEA 2022). Hence, regions endowed with richer resources are likely to experience more severe environmental challenges. (Lee & He 2022). For the first time, Humboldt proposed the theory of ecological balance, which is based on the principle that any change in an environmental factor can have a chain effect on other environmental factors; for example, over-extraction of natural resources can lead to a reduction in water and soil resources, destruction of natural habitats, and climate change (Jahangard 2018). Indeed, oil and gas exploration and extraction activities include multiple stages, as: exploration, construction, installation, extraction, production, transportation, and decommissioning, each of which creates pollution according to the type of activity (Ebrahimi et al. 2016). Danish et al (2019) argued that oil and gas extraction lead to the leakage of toxic chemical contaminants into the water, where, processing and transition of oil and gas lead to deforestation, air pollution, and limitation of agricultural production. In addition, consuming fossil fuels in all stages of natural resource extraction leads to increased greenhouse gas emissions and global warming (Ahmed et al. 2020). Kwakwa et al (2018) and Wu et al (2017) stated that continuous extraction of natural resources can fuel environmental degradations through an increase in energy consumption, air and water pollution, destruction of natural habitats, and decrease in biodiversity. A large number of studies explain how natural resource extraction destroys fishing grounds[4]. In this context, Razzaghi and Fotros (2024) argued that fossil fuel extraction causes toxic microplastic smog, noise pollution, and artificial lightening which resulting in alterations in fish migration patterns, breeding behavior, and feeding habits. Chekouri (2023) shows that higher natural resource extraction intensifies the ecological footprint in Algeria, while lower extraction may have less harmful effects. Makhdum et al. (2022) show that natural resources noticeably increase ecological footprint levels in the short and long term in China.

2.2. The ecological footprint of economic growth

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[3] For example, the coal capital of China, Shanxi province, is known as the most polluted city in the world.

[4] See for example: Sharif et al (2020), Danish et al. (2019) and Hassan et al. (2019) among others

According to economic theories, the human activities arising from economic development (shown by GDP and GDP^2 in the early and advanced stages of development, respectively) have adverse effects on the environment. Kolstad & Golub (1993) believe that economic growth and increased production require greater use of natural resources and energy, especially fossil fuels, which in turn leads to environmental degradation. In addition, economic development leads to importing energy-intensive technologies (especially in oil-rich countries), industrialization, urbanization, infrastructures and more international trade that all cause pollution haven (Cole 2004). However, in the advanced levels of development, public awareness of the necessity of a sustainable environment rises which leads to the establishment of legislative and regulatory institutions to protect the environment (Ahmed et al, 2021). Gradually, increasing the use of renewable energy, reducing the use of fossil fuels, and other protectionary actions subside the destructive environmental effects of economic growth (Khezri et al. 2023a). This relationship between economic growth and environmental quality is known as the inverted U-shaped Environmental Kuznets Curve, which was first proposed by Grossman and Krueger (1991, 1995). The results of empirical research about the existence of the environmental Kuznets Curve are mixed. For example, Arif et al (2023), and Ullah et al. (2023) confirm the environmental Kuznets curve (EKC) hypothesis for Pakistan and Turkey. However, Li et al. (2023) rejects the environmental Kuznets curve in 158 countries.

2.3. The ecological footprint of urbanization

The relationship between urbanization and environmental quality is still uncertain. Urbanization shows the process of rural people's migration to urban areas which is associated with rapid industrialization, population growth and social and economic structural changes (Hashmi et al. 2021). Some theories argue that urbanization is accompanied by increased energy consumption and exploitation of natural resources resulting in carbon dioxide emission. In addition, urbanization increases demand for more transportation infrastructures, increases deforestation to accommodate expanding human habitats, increases consumption of crop lands, and livestock, increases demand for manufactured products, increases discharge of factory waste material into the environment, which all lead to environmental degradations (Salman et al. 2022, Ahmed et al. 2020). However, other theories argue that modernity could decrease ecological devastation by applying advanced clean technologies (such as renewable energy) and using energy more efficient (Fan et al. 2006). In this context, Sarwar et al (2024) showed that urbanization increases the ecological footprint in OECD countries and decreases the ecological footprint in non-OECD countries. Ullah et al. (2023) showed that urbanization hurting the ecological footprint in Turkey.

2.4. The ecological footprint of inequality

The impact of income inequality on ecological footprint is significant. According to Jorgenson et al (2017) as the income gap among households gets raised, then consumption competition and working long hours occur in society that aggravate environmental pressure. Ravallion et al (2000) argue that income inequalities could change consumers' preferences and change the marginal emission trend by households that affect the environment quality. People with higher incomes excessively consume more natural resources and they have more willingness to buy goods and services that can increase waste and environmental pollution. The lower-income consumers also apply more inefficient technologies and goods in their consuming bundle that could devastate the environment (Uzar and Ayupoglu 2022). In addition, Wolde-Rufael and Idowu (2017) argue that income inequalities result in an undemocratic decision-making process which disrupts the implementation of environmental protection policies and then the high-income groups could implement their economic projects and impose environmental costs. However, the Keynesian effect introduces a different mechanism in the relationship between income inequality and ecological degradation. According to the Keynesian effect, the reduction of the income gap among social groups encourages lower-income groups to demand activities such as heating, electricity, transportation, and travel, which are closely related to pollution emissions (Ravallion et al. 2000). The results of empirical studies are conflicting. Idrees et al (2022), Uzer and Ayupoglu (2022), and Kazemzadeh et al (2021) showed that income inequality promotes environmental pollution; however, Anderson (2024) argued that the relationship between income inequality and ecological footprint is insignificant. Langnel et al

(2021) show that income inequalities improve environmental quality in Burkina Faso, Nigeria, and Senegal and worsen it in Benin.

2.5. The ecological footprint of foreign direct investment

Foreign direct investment (FDI) is one of the best solutions to trigger economic development in developing countries. FDI brings new knowledge, technology, and new methods of management to the host countries and has three different effects on the supply side of the host economy such as 1) scale effect: it refers to stimulating economic activities and occurring big-push in the host economy where a large proportion of environmental degradation is rooted in the intensification of economic activities. 2) Composition effect: it refers to changing the mixture and the combination of industries in host countries. The environmental outcome depends on the nature of industries that are interred to receiving countries through foreign direct investment. 3) Technological effect: it refers to new production and management knowledge and technologies that are transferred to the host country by FDI that make the production phase more productive and efficient. Therefore, the environmental degradation effects of manufacturers are reduced (Doych 2020). On the demand side, foreign direct investment increases household income which leads to increased consumption demand by households (in the case of equal income distribution) that raises environmental degradations (Doych 2020). In this concept, Jahangir et al. (2023) show that technological innovation is crucial in reducing the adverse environmental effects of natural resource consumption across all regions in 73 developing countries.

In addition, the empirical literature on the nexus between FDI and ecological footprint examines three kinds of hypotheses: 1) the pollution haven hypothesis 2) the FDI halo hypothesis and 3) the Environmental Kuznets curve. According to the pollution haven hypothesis, foreign investors are more eager to invest in countries with low regulatory policies on conserving the environment. Then they impose the destructive environmental burden of their production and consumption on developing countries (Gallagher 2009). The FDI halo hypothesis explains how multinational firms in less developed countries could awaken public opinion regarding environmental protection policies in host countries (Jorgenson 2007). Finally, according to the environmental Kuznets curve, the deterioration of the environment increases in the first stages of industrialization triggered by FDI, and at the high level of economic growth these degradations will be decreased (Dinda 2004). Kızılgöl & Önde (2022) show that foreign direct investment decreases ecological footprint in 31 OECD countries.

2.6. Ecological footprint of renewable energy

According to most theories and empirical studies, energy is at the heart of environmental degradation. Energy production and consuming traditional energy sources such as oil, coal, and natural gas damage ecological quality by polluting the air and releasing greenhouse gases. Burning fossil fuels raises global temperature and causes climate change. It is expected that utilizing renewable energy based on wind, water, sun, and waste can gradually reduce pressure on the environment and guarantee environmental sustainability (Chen et al. 2019). However, the nexus between ecological footprint and renewable energy consumption is complex. For example, Akpanke et al (2024) released that consuming renewable energy in OECD countries significantly reduced ecological footprint and carbon emission. Azimi and Mohammad (2024) argued that there is a nonlinear relationship between renewable energy and ecological footprint in 74 developing countries and consuming renewable energy mitigates the ecological damages. Abid et al (2022) showed that renewable energy consumption in Saudia Arabia caused environmental quality progress. Nan et al (2022) argued that renewable energy has a long-term negative impact on the ecological footprint in China. In contrast, Raghutla et al (2022) showed that renewable energy consumption increases the ecological footprint in N-11 countries. In addition, Nathaniel et al (2022) showed that renewable energy usage couldn't control the ecological footprint in emerging countries. Ansari et al (2021) also found that renewable energy harms the environment. Kongbuamai et al (2021) found that renewable energy's growth led to environmental degradation growth.

3. Model Specification and Data

To examine the spillover effects of gas extraction on ecological footprint in the Middle East area, this study applied Karimi et al. (2022) conceptual model as follows:

$$\ln EFP_{it} = \beta_1 + \beta_2 \ln GDP_{it} + \beta_3 \ln GDP_{it}^2 + \beta_4 \ln GINI_{it} + \beta_5 \ln FDI_{it} + \beta_6 \ln URB_{it} + \beta_7 \ln EC_{it} + \beta_8 \ln REC_{it} + \beta_9 \ln GAS\ EX_{it} + \varepsilon_{it} \quad (6)$$

Where EFP indicates Ecological Footprint Index as the dependent variable, GDP shows gross domestic production, GDP^2 is the squared form of gross domestic production[5], GINI is the Gini coefficient, FDI is foreign direct investment, URB is urbanization, EC is energy consumption, REC is renewable energy consumption, and GAS EX is gas extraction. A detailed description of the research variables is presented in Table 1.

Table 1: Description of Variables

	Variables	Theoretical definitions	Operational Definitions	Source
Dependent	EFP	environmental pressure of human activities by measuring the biologically productive land and water area required to supply consumed resources and absorb generated waste, given existing technology and management practices.	Global Hectares per person	GFN
Independent	GDP	Gross Domestic Product (GDP) is an economic indicator that measures the total monetary value of all final goods and services produced within a country's borders over a specific period	Real GDP (constant 2015US$)	WDI
	Gini	measure of income inequality that summarizes the extent to which income distribution within an economy deviates from perfect equality, with higher values indicating greater inequality	standardized Gini index, ranging from 0 (perfect equality) to 100 (perfect inequality)	WDI
	FDI	Foreign Direct Investment (FDI) refers to cross-border investment in which a resident entity in one country obtains a lasting interest and a significant degree of influence in the management of an enterprise operating in another country, facilitating capital accumulation, technology transfer, and production expansion.	net inflows of foreign direct investment as a percentage of GDP	WDI
	Urban	Urbanization refers to the process by which an increasing proportion of a country's population resides in urban areas, reflecting structural changes in economic activity, land use, and consumption patterns that can intensify environmental pressure.	percentage of the total population living in urban areas	WDI
	EC	Energy consumption refers to the total amount of energy used by economic agents within an economy to support production, transportation, and household activities, and is a key driver of economic growth and environmental pressure through resource use and emissions.	per capita energy use, measured in kilograms of oil equivalent	EIA
	REC	Renewable energy consumption refers to the use of energy derived from naturally replenishing sources such as solar, wind, hydro, biomass, and geothermal	share of renewable energy in total final energy consumption	EIA
	Gas ex	Gas extraction refers to the process of locating, drilling, and producing natural gas from underground reservoirs	natural gas production in billion cubic meters (bcm),	IEA

Source: Author. Note: GFN – Global Footprint Network, WDI – World Development Indicators, IEA – International Energy Agency, EIA-Energy Information Administration

[5] The squared form of GDP is included in the model to capture nonlinear relationships between economic growth and environmental pressure, specifically to test the Environmental Kuznets Curve (EKC) hypothesis. According to the EKC theory, at early stages of economic development, environmental degradation (e.g., ecological footprint) tends to increase with income due to higher industrial activity, energy use, and consumption. However, after a certain level of income is reached, further growth leads to improvements in environmental quality as societies adopt cleaner technologies, implement stricter regulations, and shift toward service-oriented economies.

Figures 1 and 2 illustrate the increasing trend of natural gas extraction and the corresponding upward trend in the ecological footprint in gas-rich countries of the Middle East from 2000 to 2021. According to Figure 1, countries such as Iran, Qatar, and Saudi Arabia have experienced a particularly sharp increase in natural gas extraction during the last decade compared to the previous one, while other countries in the region show a more moderate rise. Simultaneously, as shown in Figure 2, the average ecological footprint in these countries has also increased over the same period. This parallel rise suggests a strong link between intensified gas extraction and increased environmental pressure. In particular, the data indicate that countries with the most aggressive extraction policies not only face local ecological impacts, such as land degradation and water stress, but may also contribute to regional environmental pressures through cross-border effects.

Additionally, the figures highlight heterogeneity among Middle Eastern countries: while some nations maintain relatively stable extraction and ecological footprints, others exhibit a steep upward trajectory, reflecting differences in energy policies, technological adoption, and resource management strategies. The combined interpretation of Figures 1 and 2 underlines the environmental costs of rapid energy expansion in the region and emphasizes the need for implementing sustainable extraction practices and regional environmental cooperation to mitigate these impacts.

Fig .1: Gas Production During 2000 to 2021

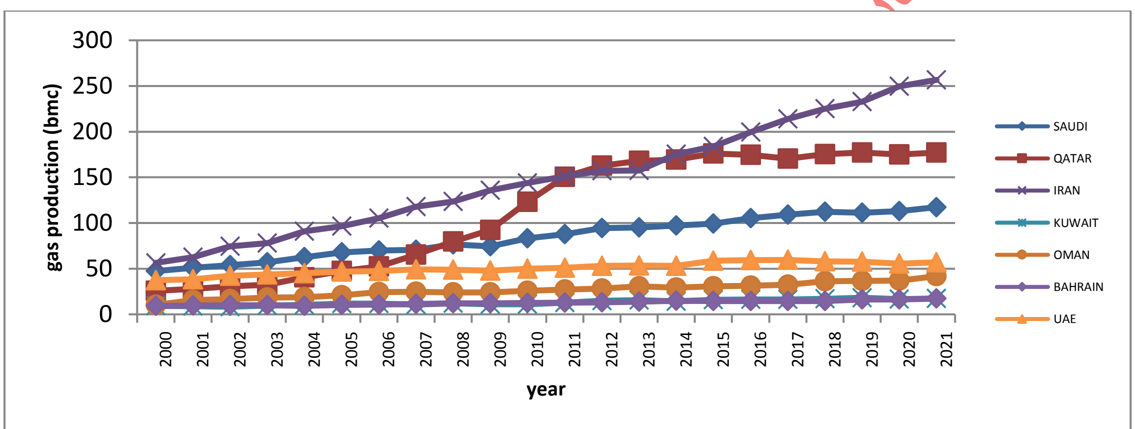
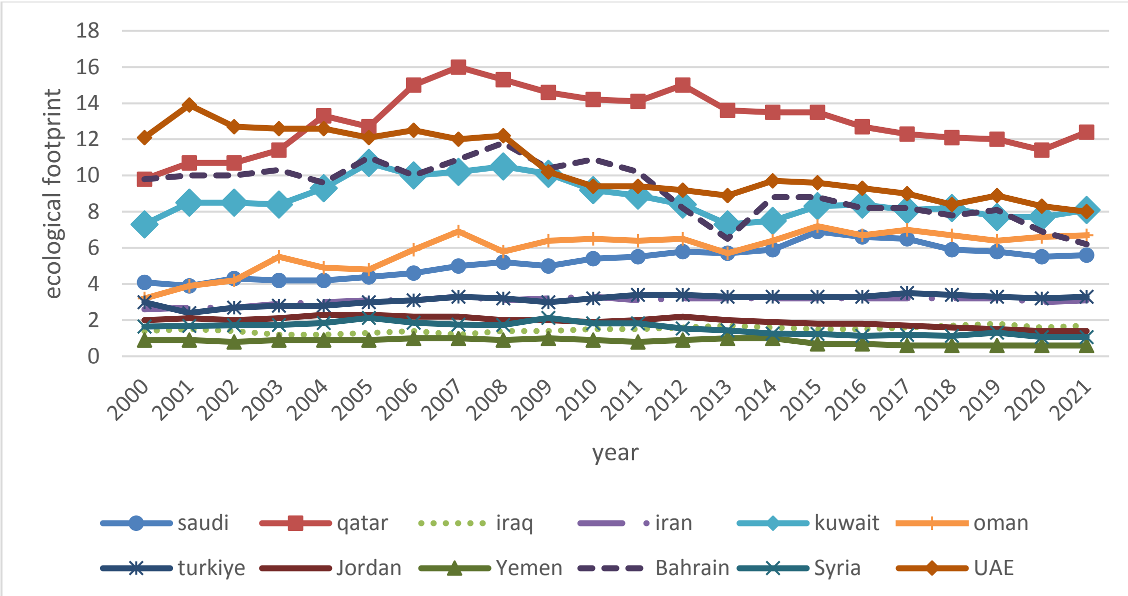


Fig. 2: Ecological Footprint During 2000 to 2021



3. Methodology and Data

Analyzing the spatial interaction effects is a considerable issue in regional span studies. Many scientific theories and empirical observations in environmental studies show that changes to explanatory variables in a unit country i could change the dependent variable not only in country i, but also in neighboring countries of j. Based on the hypothesis of Wang et al. (2016) that "all issues related to environmental problems are inherently spatial", this study utilizes a spatial panel data methodology to consider spillover effects. Spatial panel data econometrics considers the interaction among economic units which originates from physical (spatial) conditions or economic characteristics. In general, there are three types of spatial interaction effects which consumed as: endogenous interaction effects (where the dependent variable of a country is affected by the dependent variable of a neighboring country), exogenous interaction effects (where the dependent variable of a country is affected by independent variables of neighboring country), and interaction between error terms (where the error term of a country is affected by error terms of neighboring country and the error terms are spatially correlated) (Elhorst 2017).

The general nesting spatial panel data model is as follows (Belotti et al. 2017):

$$Y_{it} = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij} Y_{jt} + \sum_{k=1}^{k} X_{itk} \beta_k + \sum_{k=1}^{k} \sum_{j=1}^{n} W_{ij} X_{jtk} \theta_k + \mu_i + \gamma_t + \nu_{it}$$

$$\nu_{it} = \lambda \sum_{j=1}^{n} W_{ij} \nu_{it} + \varepsilon_{it} \;; \quad i = 1,2,\ldots,n\,; \quad t = 1,2,\ldots,T; \qquad (1)$$

Where Y_{it} represents the dependent variable, X denotes the explanatory variables ranging from 1 to k, W_{ij} is the spatial weight matrix and $W_{ij}Y_{jt}$ indicates the spatial lag effect of the dependent variable Y_{jt} on Y_{it} . ρ represents the coefficient of spatial autoregressive. β_k and θ_k represent the non-spatial and spatial effects of the explanatory variables, respectively. α denotes the intercept, μ_i represents the spatial fixed (random) effects, and γ_t denotes the time fixed effects. Additionally, with the presence of the τ coefficient, the model can be both static and dynamic. In the static model, τ=0, while in the dynamic model, τ≠0. In addition, ν_{it} is the error term of the model that can also incorporate spatial effects, and λ represents the spatial effect from the error terms named spatial autocorrelation coefficient. The general nested spatial model is rarely used because of overfitting problems. However, based on the variety of spatial dependencies between countries, some of the regular different variants of spatial regression models are as follows:

1. The Spatial Autoregressive model (SAR): captures the endogenous interaction effects, where the dependent variable's disturbance term depends on the neighboring dependent factor.

$$(\lambda = \theta = 0) \Rightarrow Y_i = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij} Y_{jt} + \sum_{k=1}^{k} X_{itk} \beta_k + \mu_i + \gamma_t + \nu_{it} \quad (2)$$

2. The Spatial Error Model (SEM): captures the interaction effect among the error terms.

$$(\rho = \theta = 0) \Rightarrow Y_i = \alpha + \tau Y_{i,t-1} + \sum_{k=1}^{k} X_{itk} \beta_k + \mu_i + \gamma_t + \nu_{it}$$

$$\nu_{it} = \lambda \sum_{j=1}^{n} W_{ij} \nu_{it} + \varepsilon_{it} \quad (3)$$

3. The Spatial Autoregressive with Spatial Autoregressive Combined Model (SAC): captures both endogenous interaction effect and error interaction effect.

$$(\theta = 0) \Rightarrow Y_{it} = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij} Y_{jt} + \sum_{k=1}^{k} X_{itk} \beta_k + \mu_i + \gamma_t + \nu_{it}$$

$$\nu_{it} = \lambda \sum_{j=1}^{n} W_{ij} \nu_{it} + \varepsilon_{it} \quad (4)$$

4. The Spatial Durbin Model (SDM): captures both endogenous and exogenous interactions.

$$(\lambda = 0) \Rightarrow Y_{it} = \alpha + \tau Y_{i,t-1} + \rho \sum_{j=1}^{n} W_{ij} Y_{jt} + \sum_{k=1}^{k} X_{itk} \beta_k + \sum_{k=1}^{k} \sum_{j=1}^{n} W_{ij} X_{jtk} \theta_k + \mu_i + \gamma_t + \varepsilon_{it} \quad (5)$$

In order to justify the application of spatial model, the presence of spatial autocorrelation and special dependencies should be examined. In this context, the LM test, Moran's test, Geary-C test, and Getis-ords test applied. The LM test examines the null hypothesis of $\rho = 0$, and existence of spatial autocorrelation among observations is approved by the rejection of null hypothesis. The Moran's I test, Geary-c test, and Getis-ords examine the null hypothesis of $\lambda = 0$ where the rejection of this hypothesis indicates the existence of spatial autocorrelation among error terms.

In addition, the spatial weighting matrix (W) specifies the values of spatial aspects in the model. It shows how much potential spillover there is from one country to another neighboring country. The elements of this matrix are based on the contiguity, revealing the border sharing among countries. Zero element in this matrix shows that two countries share no water or land border, hence no spillover effect could exist between them. In addition, number 1 element in the contiguity matrix shows that two countries share common borders and the potential for spillover effects between two countries is very high.

4. Model Estimation

Before estimating the model to analyze the spillover effects of ecological footprint in the Middle Eastern countries, the stationarity of the variables was tested and reported in Table 2. The results using the Levin et al (2002) test indicate that all variables are stationary at a significance level of 5%.

Table 2: results of stationary test

Variables	Test statistics	prob	result
$\ln EFP_{it}$	-1.84	0.032	Stationary
$\ln GDP_{it}$	-3.96	0.000	Stationary
$\ln GDP_{it}^2$	-2.95	0.0016	Stationary
$\ln GINI_{it}$	-3.53	0.0002	Stationary

$\ln FDI_{it}$	-3.25	0.0006	Stationary
$\ln URB_{it}$	-5.25	0.000	Stationary
$\ln GAS\ EX_{it}$	-5.42	0.000	Stationary

In addition, Moran's I test, Geary's GC test, and Getis' G test were utilized in order to examine the existence of spatial error autocorrelations. The results of these tests are presented in Table 3.

Table 3: Diagnostic tests of spatial autocorrelation

Test Statistic	Moran-I-Statistic	Getis-Ords	Geary GC	LM Error	LM lag
Value	٠/0.1939	-0.8566	1.1505	40.8200	12.7932
(Significance level)	∗(0.000)	∗(0.0000)	∗∗(0.0509)	∗(0.0000)	∗(0.0003)

* Significance at the 1% level,∗∗ Significance at the 5% level

Based on the results of Moran's I and Getis' G tests, the existence of positive spatial dependencies among errors are confirmed. In addition, the results of the LM Error test reject the null hypothesis of no spatial autocorrelation and the results of the LM lag test confirm the existence of spatial autocorrelation among lagged dependent variables in the region. Therefore, the spillover effect of ecological footprint in the Middle East area exists and the ecological footprint of a country is not solely a result of its characteristics and location but is also influenced by other countries. Then, we are allowed to apply the spatial panel data method. After confirming the presence of spatial autocorrelation, selection between different spatial models is done using diagnostic tests. The first step in choosing the optimal model is to compare the SAR model with the SDM model using the Wald test.

Table 4: Wald test

Hypothesis Test	**Statistical Value**	Significance level
$\theta = 0$ **(SAR V.S SDM)**	86.05	0.0000

Source: Authors' estimations

According to the results of Table 4, the null hypothesis of the Wald test which states that the SAR model is optimal at a 5% significance level is rejected, and the SDM model is chosen. In the second step, the Multiple Wald test is used to compare the SEM model against the SDM model and the result is presented in Table 5.

Table 5: Multiple Wald test

Hypothesis Test	**Statistical Value**	**Significance level**
$\theta = -\beta\rho$ **(SEM VS SDM)**	84.38	0.0000

Source: Authors' estimations

According to the results, the null hypothesis which suggests the superiority of the SEM model is rejected, and the SDM model is chosen as the optimal model in this step. In the next step, Akaike's information criterion and Bayesian criterion are utilized to select the optimal model between the SAC and SDM models and the results are presented in Table 6.

Table 6: Akaike's information criterion and Bayesian information criterion

Model	Bayesian(**BIC**)	Akaike(**AIC**)
SAC	-360.0057	-399.3411
SDM	-399.2611	-463.6282

Source: Authors' estimations

According to the results in Table 5, between the SAC and SDM models, the optimal model is the SDM. A prominent feature of the spatial Durbin model compared to other spatial models is the consideration of spatial lag of the dependent variable and spatial lag of explanatory variables as new explanatory variables. The spatial Durbin model decomposes total effects into direct and indirect effects (spillover effects), meaning that linear regression parameters are interpreted through direct and indirect effects (Lesage & Pace 2009). After selecting the optimal model, the Hausman test is used to choose between models with fixed or random effects.

Table 7: Hausman test

Test Statistic	Statistical Value	Significance level
Hausman	16.85	0.4644

Source: Authors' estimations

According to the result in Table 7, the existence of random effects is accepted, indicating that our spatial Durbin model includes random effects. Therefore, we will estimate the research model, which is defined as follows for the spatial Durbin model:

$$\ln EFP_{it} = \beta_1 + \rho \sum_{j=1}^{n} W_{ij} \ln EFP_{it} + \beta_2 \ln GDP_{it} + \beta_3 \ln GDP_{it}^2 + \beta_4 \ln GINI_{it} + \beta_5 \ln FDI_{it} + \beta_6 \ln URB_{it} + \beta_7 \ln EC_{it} + \beta_8 \ln REC_{it} + +\beta_9 \ln GAS\ EX_{it} + \theta_{10} \sum_{j=1}^{n} W_{ij} \ln GDP_{it} + \theta_{11} \sum_{j=1}^{n} W_{ij} \ln GDP_{it}^2 + \theta_{12} \sum_{j=1}^{n} W_{ij} \ln GINI_{it} + \theta_{13} \sum_{j=1}^{n} W_{ij} \ln FDI_{it} + \theta_{14} \sum_{j=1}^{n} W_{ij} \ln URB_{it} + \theta_{15} \sum_{j=1}^{n} W_{ij} \ln EC_{it} + \theta_{16} \sum_{j=1}^{n} W_{ij} \ln REC_{it} + \theta_{17} \sum_{j=1}^{n} W_{ij} \ln GAS\ EX_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (7)$$

Where ρ represents the spatial effect resulting from the dependent variable, β shows the effects of explanatory variables on the dependent variable, and θ represents the neighbor effects or spillover effects of independent variables.

Table (8): Results of Spatial Models Estimation

Model / Variable		SDM Model				
		Contiguity Matrix	**Inverse Distance Matrix**		**Contiguity Matrix**	**Inverse Distance Matrix**
EFP		Coef. (z)	Coef. (z)		Coef. (Z)	Coef. (z)
Main Effects	LnGDP	0.37 (7.48)*	0.56 (11.34)***	Weighted Spatial Effects	-0.6876 (-5.99) *	0.34 (1.20)
	LnGDP²	0.0024 (1.75)***	0.003 (1.93)**		0.0094 (2.72) *	0.003 (0.78)
	LnGINI	0.16 (0.69)	0.44 (1.81)*		2.2195 (4.40) *	1.36 (1.31)
	LnFDI	-0.13	0.001		0.2883	0.28

		(-0.32)	(0.02)		(4.96) *	(1.88)**
	LnURBAN	0.43 (-6.45) *	-0.57 (-9.38)***		0.5258 (4.14) *	-0.13 (-0.46)
	LnGASEX	0.01 (1.62) ***	0.01 (1.68)***		0.0110 (0.51)	0.025 (0.48)
	LnEC	0.05 (5.62) *	0.04 (2.36)*		0.0461 (2.36) *	0.04 (2.35)*
	LnREC	-1.4664 (-1.85) ***	-1.70 (-1.9)**		1.3777 (1.14)	1.37 (1.15)
Spatial	Rho	0.0012 (0.01) ***		Number of observations	264	
R^2	Within	0.6243		Number of Groups	12	
	Between	0.5520		Panel Length	22	
	Overall	0.5491		Log-Likelihood	201.7361	

Note: **p-value, ***, **, and * show significance at 1%, 5%, and 10% levels, respectively**
Source: Authors' estimations

Table 8 shows the results of SDM model estimation, where, in order to examine the robustness of the results, the model is re-estimated using two alternative spatial weight matrices: (i) a binary contiguity matrix[6], and (ii) an inverse distance matrix constructed from the geographical distances between the countries' capital cities. The estimation results of the Spatial Durbin Model (SDM) based on the inverse distance matrix are reported in Table 8 and highlighted in grey. Based on the results, the estimated spatial Rho coefficient is positive and considerably significant at a 99% confidence level. This result indicates that the ecological footprint determinants in a country have spillover effects in neighboring countries around the Middle East region. In addition, according to the results, local natural gas extraction has a strictly positive and significant effect on the ecological footprint. Each percent increase in gas extraction leads to approximately 0.01 increase in ecological footprint in the home country. The Middle East region contains developing countries which are endowed with enormous natural resources and their economy is mostly based on oil and gas export. They always increase the amount of natural resource extraction in order to support the increasing trend of global energy demand. These countries not only suffer from insufficient technologies and up-to-date methods of exploitation, but the lack of environmental protection policies has also contributed to environmental degradation. This result is consistent with the results of Razzaghi and Fotros (2024), who concluded that gas extraction destroys the environment in the Middle East, and is inconsistent with the results of Zeraibi and Khan (2024) who showed that gas extraction reduces the ecological footprint in the USA. In addition, according to the spatial coefficients released in Table 7, the spillover effects of gas extraction in the Middle East region are insignificantly positive. It means that the adverse spillover effect of the gas extraction process in the home country on the ecological footprint in neighboring countries is not considerable.

In the context of the Environmental Kuznets Curve (EKC) hypothesis, the effects of local GDP and squared form of GDP on the ecological footprint in the home country are positive and significant which means that the higher the GDP, the larger the ecological footprint, resulting in environmental degradations. According to the EKC hypothesis, economic growth initially leads to increased environmental degradation, but after reaching a certain level of economic growth, environmental quality improves. Therefore, our results reject the EKC hypothesis. This result indicates that the environmental reservation policies are not accompanied by an economic acceleration process in the Middle East and they still prioritize economic growth issues over environmental concerns, leading to an increase in the ecological

[6] The spatial contiguity matrix is constructed such that two countries are considered neighbors if they share at least one common land or maritime boundary.

footprint in the region. This result is in line with the results of Razzaghi and Fotros (2024) and Luzzati and Orsini (2009) who strictly reject the existence of the Environmental Kuznets Curve hypothesis in the Middle East area.

According to the results in Table (8), the effect of foreign direct investment (FDI) in the home country on the local ecological footprint is not significant. Whereas, according to the estimated spatial coefficients in Table 7, the FDI in the home country has a negative and significant effect on the region-wide ecological footprint. This result is in line with the results of Doych (2020), and Gallagher (2009). If foreign direct investment were accompanied by the transferring of clean and efficient technologies to the host country, as well as compliance with environmental standards and investment in sustainable projects, then the destructive effects of FDI would be reduced. However, most foreign direct investments in the Middle East area are in energy industries or mostly are based on energy-intensive technologies which intensify energy consumption and adversely impact the environment.

The main and the weighted spatial coefficients presented in Table 8 indicate that the Gini variable positively and significantly affects the ecological footprint and raises environmental degradations locally and region-wide in the Middle East area. These results show that increasing income inequality leads to consumption competition between low-income and high-income households and working for long times which consequently triggers resource consumption and leads to high environmental degradations. This result is consistent with the results of Idrees et al (2022) and Uzer and Ayupoglu (2022).

Further, since urbanization is associated with modernization, it mitigates environmental pressures. Accordingly, the relationship between urbanization and the ecological footprint in this region is significantly negative. However, the spillover effect of urbanization on the level of ecological footprint in neighboring countries is positive. In addition, the effect of energy consumption on ecological footprint in the Middle East area is significantly positive, locally and regionally. As the production process and the household consumption pattern in the Middle East are deeply energy-intensive, then energy consumption degrades the environment. Renewable energy consumption also has a considerable negative effect on the ecological footprint in this region. These results confirm the results of Akpanke et al (2024) and Abid et al (2022).

In order to gain further inferences, we decomposed coefficients into direct, indirect and total effects. The direct and indirect effects are marginal effects of the changes in explanatory variables on the dependent variables and show how a 1 per cent change in an explanatory variable leads to a change in ecological footprint in home and neighboring countries, respectively. The total effect shows the sum of direct and indirect effects. The results of coefficient decomposition are presented in Table 9, below.

Table (9): Results of Direct Effects,Indirect Effects and Total Effects.

Model		SDM		
	Variable	Coef. (Significance level)	Std. Err	Z
Direct	LnGDP	0.3804(*)	0.5053	7.53
	$LnGDP^2$	0.0023 (***)	0.0013	1.79
	LnGINI	0.1846	0.2203	0.84
	LnFDI	-0.1286	0.0410	-0.31
	LnURBAN	-0.4361 (*)	0.0629	-6.93

	LnGASEX	0.0156 (**)	0.0092	1.70
	LnEC	0.0566 (*)	0.0103	5.46
	LnREC	-1.5006 (**)	0.7519	-2.00
Indirect	LnGDP	-0.6909 (*)	0.1202	-5.74
	$LnGDP^2$	0.0093 (*)	0.0034	2.73
	LnGINI	2.1994 (*)	0.4900	4.49
	LnFDI	0.2819 (*)	0.0572	4.92
	LnURBAN	0.5293 (*)	0.1270	4.16
	LnGASEX	0.0103	0.0208	0.50
	LnEC	0.0462 (**)	0.0196	2.35
	LnREC	1.5107	1.2341	1.22
Total	LnGDP	-0.3104 (**)	0.1382	-2.25
	$LnGDP^2$	0.0117 (*)	0.0037	3.14
	LnGINI	2.3840 (*)	0.4768	5.00
	LnFDI	0.2690 (*)	0.0703	3.83
	LnURBAN	0.0931 (**)	0.1344	0.69
	LnGASEX	0.0260 (***)	0.0240	1.08
	LnEC	0.1029 (*)	0.0259	3.96
	LnREC	0.0100	1.4767	0.01

Note: p-value, *, **, and * show significance at 1%, 5%, and 10% levels, respectively**

Source: Authors' estimations

The predominant driving factors of ecological degradation inside a country located in the Middle East are GDP, energy consumption, and gas extraction operation, respectively. In addition, the findings reveal significant and noteworthy direct and total effects of gas extraction on the ecological footprint. The direct impact of gas extraction on the ecological footprint at a 5% level is notably positive, increasing the ecological footprint in the home country by an average of 0.015. However, the indirect effect of natural gas extraction on the ecological footprint of neighboring countries is positive but insignificant. A 1% increase in gas extraction leads to a 0.02 increase in environmental degradations all over the Middle East region. These results align with the results of Nassani et al. (2021) and Ben Salha & Zmami (2023).

In terms of GDP and the squared form of GDP, the direct effect of these variables on the ecological footprint is positive and significant. More precisely, a one percent increase in GDP and squared form of GDP, leads to a 0.38 and 0.002 percent increase in the ecological footprint respectively, in the home country. As a large share of GDP in the Middle East region is based on natural resource extraction and consumption, then higher economic growth will lead to environmental pollution. This finding is in line with studies by Li et al. (2023), Khezri et al. (2023b), and Mrabet et al. (2021). However, the indirect effects of GDP and the squared form of GDP on the ecological footprint of neighbor countries are respectively negative and positive; indicating that accelerated economic growth in countries puts more environmental pressure on neighbor countries.

The direct effect of Urbanization on the ecological footprint is significantly negative. In other words, urbanization reduces the country's ecological footprint by an average of 0.43 percent. In general, the negative impact of the urban population on ecological footprint is consistent with the results of Ahmed et al. (2020). In terms of indirect effects, the effect of urbanization on the ecological footprint is positive and significant. This result is inconsistent with studies by Faith & Kai (2022) and Kızılgöl & Öndes (2022) and consistent with studies by Ullah et al. (2023) and Chekouri (2023). The direct effect of FDI is insignificantly positive and the indirect effect of FDI is significantly positive. This result shows that foreign direct investment in a country adversely leads to environmental degradation in neighboring countries. This result is in line with the results of Ekeocha (2021) and inconsistent with the results of (2019) Zafar, and (2004). According to the results presented in Table 8, increasing energy consumption in a country leads to considerable environmental degradation inside the country and neighboring countries. However, applying more renewable energy in this region could increase the environmental pressure inside the country, though its spillover effect is not noticeable.

5. Results and Discussions

The natural resource extraction process has multiple significant threats to environmental quality. The scope of environmental damages caused by energy extraction ranges from air pollution, water pollution, and fisheries ground pollution to ecosystem damage, deforestation, and destruction of agricultural land and construction areas in order to facilitate the transportation of oil and gas. Therefore, the Middle East is one of the most natural resource-abundant regions and faces terrible environmental stresses. The main purpose of this study is to investigate the demolition environmental effects of gas extraction in the Middle East Area. Given that the adverse environmental effects rising by gas extraction operations not only affect the home country, but also involve neighboring countries, then this study applied the spatial panel data method in order to consider these spillover effects.

The hypotheses of the existence of spatial autocorrelation among both error terms and spatial units around the Middle East region are accepted through related tests. In addition, the significant positive coefficient of ρ indicates that any change in local ecological footprint leads to a change in environmental quality in neighbor countries in the Middle East area. This result highlights the necessity of enforcing intra-regional ecological regulations in the Middle East. Environmental cooperation can be framed as technical rather than political coordination. For example, the use of environmental data-sharing mechanisms, the application of harmonized emission monitoring standards, and the establishment of transboundary pollution early-warning systems could facilitate cooperation and enhance mutual trust among countries. Enhancing oversight and coordination among countries through a regional intermediary institution can also be an effective solution in this regard. According to the results, gas extraction has a positive and significant effect on ecological footprint in home countries, although, its spillover effect is positive and not significant. Most Middle Eastern countries are categorized as developing countries and they suffer from low production diversifications, and their economies are mostly based on only energy exports. They are more eager to extract energy to achieve economic growth. In addition, they are applying obsolete technologies in the extraction process that exacerbate environmental hazards. Therefore, enacting policies that promote investment in cleaner and more efficient technologies can directly reduce the environmental burden of resource extraction. In addition, enforcing stricter environmental protection regulations, adopting policies to reduce the economy's dependence on natural resources, and strengthening the industrial foundations of the countries mentioned above can reduce their ever-increasing reliance on the extraction of natural resources that consequently results in improving environmental quality.

In addition, the environmental Kuznets curve hypothesis is rejected in this region. It indicates that the Middle Eastern countries are still moving on the left-hand side of the environmental Kuznets curve such that both GDP and ecological pollution increase simultaneously. Therefore, environmental protection policies need to be explicitly incorporated into national development plans, rather than treated as secondary concerns. Foreign direct investment in host countries affects adversely the ecological quality in neighboring countries. Indeed, the foreign direct investment inflow to the Middle Eastern countries is not accompanied by the transfer of new and cleaner technologies, reducing the ecological footprint in the region. Moreover, the bulk of the foreign investments flowed into the Middle East are mainly in energy extraction projects or apply energy-intensive technologies, which consequently leads to environmental degradation.

Thus, attracting foreign investments that are more labor-intensive rather than energy-intensive or investment projects that use new technologies should be at the top of the priorities for attracting foreign investment in these countries. Accordingly, energy consumption has a destructive effect on the environment both in the home country and region-wide. However renewable energy consumption decreases the ecological footprint in the home country. Therefore, transitioning to renewable energy sources and improving energy efficiency can reduce reliance on fossil fuels and mitigate the environmental impacts of gas extraction.

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