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Towards sustainability: Examining financial, economic, and societal determinants of environmental degradation

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ABSTRACT

We examine the determinants of environmental degradation, focusing on MENA economies from 1991 to 2020, with a particular focus on the role of sectoral composition. Specifically, we assess the contributions of the industrial, manufacturing, agricultural, and service sectors to GDP and their impact on environmental outcomes. Employing augmented mean group estimation, we evidence that technological advancements and renewable energy consumption significantly reduce environmental degradation, and that multinational corporations from developed countries transfer beneficial environmental practices to local firms in emerging regions. Results offer new insights into the impact of financial, economic, and societal factors on environmental outcomes.

1. Introduction

The global community continuously grapples with the challenge of harmonizing economic growth with environmental conservation. While economic development is essential for poverty alleviation and enhancing human well-being, the pursuit of growth often comes at the expense of environmental health, particularly when nations prioritize artificial luxury over ecological integrity (Goodell et al., 2023a; Goodell, et al., 2023b; Cheng et al., 2024; Hunjra et al., 2024). This trade-off frequently leads to increased greenhouse gas emissions, climate change, and environmental degradation, necessitating urgent interventions by policymakers and government authorities. The debate over the optimal balance between economic development and ecological preservation remains a contentious issue at all levels of discourse. Focusing specifically on the Middle East and North Africa (MENA) region, this geographical area is marked by rapid economic growth, high energy demands, and abundant natural resources (Ben Cheikh et al., 2021). The region is projected to grow by 2.4 % in 2024 and includes some of the world's largest oil exporters, such as Saudi Arabia, Iraq, and the United Arab Emirates

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(UAE). Despite its strategic economic significance, the MENA region faces numerous challenges, including political instability, social inequality, and environmental degradation (Belaïd and Al-Sarihi, 2024; Mensi et al., 2024). Iran was the world's seventh-largest emitter of CO2 in 2022, with Saudi being the eighth largest, which highlighted the issue of climate change issue in MENA region.

Recent technological advancements underscore the need for the MENA region to diversify its economy, reduce its reliance on fossil fuels, and transition towards renewable energy sources. The region possesses substantial potential for renewable energy deployment both in terms of existing resources and the potential for cost-effective implementation. For instance, the UAE has emerged as a leader in renewable energy production, exemplified by initiatives such as the Shams Solar Power Plant and the Mohammed bin Rashid Al Maktoum Solar Park. Furthermore, the UAE's National Energy and Climate Change Plan aims to increase the share of clean energy in the country's total energy mix to 50 % by 2050.

Extensive research has been conducted to examine the impacts of decarbonization, green energy solutions, renewable energy sources, and technological advancements on CO2 emissions (Li et al., 2024). However, the literature reveals inconsistent findings regarding the effects of renewable versus non-renewable energy (Al-Mulali and Ozturk, 2015). Moreover, studies exploring the role of natural resource rents (Khan et al., 2020) also report mixed outcomes. While the majority of existing studies focus on developed countries and China, there is a paucity of research analyzing these relationships in the Middle East and North Africa (MENA) region (Charfeddine and Kahia, 2019). This gap in the literature highlights the need to investigate the MENA region's role in environmental conservation. Moreover, this study places a significant emphasis on sectoral composition as a critical determinant of environmental degradation in the MENA region. By analyzing the industrial, manufacturing, agricultural, and service sectors' contributions to GDP, we aim to identify which sectors exert the most pressure on environmental resources, providing nuanced insights that are critical for targeted policy interventions.

This study aims to address the existing research gap by answering two critical questions. Firstly, it seeks to identify the determinants of environmental degradation in the MENA region by examining factors such as economic growth, natural resource rents, renewable and non-renewable energy consumption, foreign direct investment, urbanization, and gross capital formation from 1991 to 2020. Additionally, it will assess the role of technological innovation in mitigating environmental degradation. Secondly, it investigates the impact of sectoral composition—specifically, the contributions of the industrial, manufacturing, agricultural, and services sectors to GDP—on environmental degradation in the MENA region. By providing a comprehensive analysis of the interplay between economic activities and environmental outcomes, this research aims to contribute to the identification of effective strategies for sustainable development in the MENA region.

The study uses CO2 emissions, ecological footprint, and greenhouse gas emissions as proxies for environmental degradation. It incorporates various explanatory variables, including economic growth, renewable and nonrenewable energy consumption, resource rents, technological innovation, urbanization, foreign direct investment, and gross capital formation. The objective is to provide valuable insights into how MENA countries can achieve sustainable economic growth while reducing their environmental impact. By identifying the economic sector with the most significant environmental impact, policymakers can formulate targeted policies to reduce carbon emissions and combat climate change.

Previous studies have primarily focused on factors influencing CO2 emissions, but this research introduces new perspectives. Firstly, it integrates resource rents, often overlooked in prior research, to better understand the role of natural resource earnings in CO2 abatement efforts. This is particularly relevant for the MENA region, where resource-rich nations have greater potential to generate renewable energy and mitigate environmental degradation compared to resource-poor nations reliant on energy imports, which contribute to pollution (Balsalobre-Lorente et al., 2022). Secondly, the study employs multiple measures of environmental performance, including CO2 emissions, CO2 footprint, greenhouse gas emissions, and ecological footprint, to provide a comprehensive view of climate change. The ecological footprint accounts for various aspects of environmental degradation caused by human activities and serves as a robust indicator of environmental quality (Nathaniel and Khan, 2020). Thirdly, the study examines both short- and long-term relationships using the augmented mean group (AMG) estimator, which accounts for cross-correlation across panel sections and heterogeneity in slope parameters. This approach is expected to yield more accurate and reliable results by addressing heterogeneity and cross-sectional dependence within the panel data, which are critical in the MENA region. Unlike traditional methods such as Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), the AMG method provides more robust estimates. (Eberhardt, 2012) demonstrated that the AMG approach effectively mitigates biases associated with cross-sectional dependence and slope heterogeneity, making it particularly suitable for our study's dataset. Finally, this study provides a comprehensive analysis of the MENA region's impact on environmental degradation and conservation, focusing on renewable energy and technological development. Through this multifaceted approach, the research aims to contribute significantly to the understanding of sustainable development strategies in the MENA region.

The study's findings have several practical implications. For instance, the successful deployment of renewable energy projects in Germany and Denmark offers valuable lessons for the MENA region. Policies such as feed-in tariffs, government subsidies, and public-private partnerships have been crucial in these countries. Adopting similar strategies, tailored to the socio-economic conditions of MENA countries, can facilitate the transition to renewable energy. Economic growth alone does not reduce greenhouse gas emissions and ecological footprints, which typically harm the environment. Regulations must balance environmental preservation and economic growth (El Khoury et al., 2023) and natural resource rent policies need to ensure sustainable practices and minimize degradation. Shifting resources from resource-rich sectors to manufacturing can benefit from natural resource rents while ensuring sustainability. Investments in energy-efficient technologies and reducing dependency on nonrenewable energy are essential. The correlation between gross capital formation and environmental degradation implies that long-term investments should be prioritized. Given the poor correlation between technical development and environmental quality, regulations that support environmentally friendly technology, energy efficiency, and natural resource management are necessary. Foreign direct investment (FDI) can help MENA countries overcome obstacles by attracting capital, transferring technology, and fostering industry development. Policies promoting connections between foreign and domestic companies are essential to leverage FDI for economic development.

The paper is structured as follows. Section 2 reviews the relevant literature. Section 3 details the dataset and econometric models used for analysis, specifying variables, measurement parameters, data sources, and anticipated directional signs. In Section 4, empirical findings are presented and discussed. Finally, Section 5 concludes the paper, summarizing key findings, discussing their implications, and suggesting avenues for future research.

2. Literature review

2.1. Economic growth and environment

The Environmental Kuznets Curve (EKC) hypothesis explores the interplay between economic growth and environmental quality, positing a U-shaped relationship (Li et al., 2024). Initially, economic growth exacerbates environmental degradation through increased resource consumption and pollution. However, beyond a certain income threshold, further economic growth can lead to environmental improvements due to cleaner technologies, stringent regulations, and a shift towards service-based economies. Three primary channels illustrate these dynamics. Firstly, the scale effect suggests that increased production must be matched with technological advancements to curb raw material overconsumption and waste generation, thereby mitigating environmental degradation (Ulucak et al., 2020). This relationship varies with a country's income level, where higher incomes facilitate technological progress and regulatory measures that enhance environmental quality. Secondly, the technical effect underscores the role of eco-friendly technologies in reducing environmental harm (E. Dogan and Seker, 2016). By adopting cleaner technologies, firms can significantly lower their ecological footprint, mitigating the adverse environmental impacts typically associated with economic growth. Lastly, the composition effect highlights the influence of sectoral shifts on pollution levels. As economies transition from manufacturing to service-oriented structures, material consumption declines, reducing negative environmental impacts.

2.2. Renewable energy, non-renewable energy, and environment

Economic development, while essential for improving living standards, often results in increased fossil fuel emissions, which drive industrialization and growth. Fossil fuels, though critical, are finite and significant contributors to environmental pollution, including greenhouse gases (Wang et al., 2018). In contrast, renewable energy (REN) sources such as wind, solar, and hydro are sustainable and provide cleaner energy with reduced environmental pollution. REN sources have a much lower carbon footprint, making them environmentally superior to non-renewable energy sources and crucial for achieving Sustainable Development Goals (SDGs). Research highlights the contrasting effects of renewable and non-renewable energy on the environment, generally showing that renewable energy leads to positive environmental outcomes while non-renewable energy has detrimental effects (Paramati et al., 2017). Studies consistently find a negative relationship between renewable energy use and CO2 emissions (Dhiaf et al., 2021). Clean energy adoption reduces environmental footprints and mitigates emissions in various regions, including OECD countries (Destek and Sinha, 2020), G7 countries (A. Dogan and Pata, 2022), E7 economies (Bekun et al., 2021), and USA (Pata et al., 2023). Additionally, clean energy positively affects environmental quality in developing countries (Adebayo et al., 2023). However, some studies suggest that energy consumption, regardless of the source, can negatively impact the environment, influenced by factors like geography, regulations, and income levels. While renewable energy generally contributes to reducing CO2 emissions and improving environmental quality, the impact of energy consumption on the environment can vary based on several factors. Further research is needed to understand these dynamics better and to develop effective policies for sustainable energy use (El Khoury et al., 2023).

2.3. Natural resources, technology, and environment

The relationship between natural resources and environmental impact is explored through various theories, including the treadmill of production, endogenous growth, and ecological modernization theories. Murphy (2000) introduces the ecological modernization theory, highlighting how developed nations address environmental challenges amid finite non-renewable resources and rapid economic growth causing environmental harm. The treadmill of production theory, as discussed by Schnaiberg and Gould (2000), posits that economic growth and resource extraction lead to environmental degradation due to the overuse of natural resources. In contrast, the endogenous growth and ecological modernization theories argue that technological advancements can support sustainable economic growth and environmental protection. These advancements improve productivity, reduce material consumption, and encourage the adoption of cleaner technologies (Kostakis, 2024; Xu et al., 2023). Countries with abundant natural resources may more easily transition to renewable energy, reducing environmental damage. Empirical studies present mixed findings on the impact of natural resources on CO2 emissions. Khan et al., (2020) argue that technological innovation reduces CO2 emissions in BRICS countries. (Xu et al., 2023) conclude that economic growth can indirectly improve urban environmental capacity through technological and educational advancements.

Technological innovation encompasses the creation of novel technologies and the inventive application of existing technologies. Numerous studies have investigated the influence of technology on CO2 emissions using various indicators, including research and development (R&D) efforts, efficiency, and patent development. (C. Cheng et al., 2021) analyze how it mitigates CO2 emissions in OECD countries. (Razzaq et al., 2023) investigate the asymmetric effects of climate technologies and recycling on carbon emissions in the USA. (Chen and Lee, 2020) provide cross-country evidence on the effectiveness of technology in reducing CO2 emissions. While many studies unanimously acknowledge the positive role of technology in reducing CO2 emissions or enhancing environmental quality, contrasting research suggests that it can also lead to higher emissions. Given the lack of consensus among previous studies, further research is crucial to understand the nuanced impact of technology innovation on CO2 emissions and environmental quality.

2.4. Urbanization and environment

The impact of urbanization on the environment is a contentious issue among researchers, with varying perspectives on whether urbanization leads to environmental degradation or improvement (Nathaniel and Khan, 2020). The debate centers on the extent to which urbanization influences the use of natural resources and the resultant environmental footprint. Some researchers argue that urbanization, particularly when inadequately planned, exacerbates environmental degradation by increasing the consumption of natural resources. Studies conducted by (Pata, 2018) for Turkey and (Bai et al., 2019) for China report that urbanization drives up CO2 emissions, further highlighting its detrimental effects on the environment. Conversely, other studies present a more nuanced view, suggesting that sustainable urbanization can mitigate some negative environmental impacts. Balsalobre-Lorente et al. (2022) find an inverse relationship between urbanization and CO2 emissions in BRICS countries, implying that urbanization might contribute to environmental improvements under certain conditions. Other scholars argue that urbanization reduces the EF in BRICS nations, while (Nathaniel and Khan, 2020) find no significant impact of urbanization on the EF in six ASEAN countries.

2.5. Foreign direct investments, gross capital formation, and environment

FDI influences receiving economies through scale, composition, and technological effects. The "scale effect" refers to increased economic activity due to new investments, which can exacerbate environmental degradation through higher waste and pollution levels. The "composition effect" involves structural changes in industry mixes, where the environmental impact of FDI depends on whether expanding industries are environmentally harmful or beneficial. The "technological effect" entails the diffusion of advanced technologies that can enhance productivity and potentially reduce environmental harm. Several theories explain the impact of FDI on CO2 emissions, including the Environmental Kuznets Curve, the Pollution Haven Hypothesis (PHH), and the Pollution Halo Hypothesis. PHH suggests that FDI leads to increased environmental emissions by driving economic expansion and energy use, and by shifting polluting industries to countries with lax environmental regulations. This results in higher CO2 emissions in developing nations receiving FDI. The race-to-the-bottom hypothesis further argues that lax regulations in open economies lead to environmentally harmful production practices to reduce costs. Conversely, the Pollution Halo Hypothesis posits that FDI can lower environmental emissions. Foreign firms often employ cleaner, more energy-efficient production methods and introduce advanced technologies that domestic firms can emulate, leading to overall reductions in emissions through technology spillover effects.

The effectiveness of FDI in reducing emissions depends on domestic economic characteristics, such as the ability to absorb and implement global technologies. Adequate technology spillover is essential for FDI to have a positive environmental impact. The relationship between capital formation and environmental quality is less explored and shows mixed results.

3. Data and methodology

3.1. Data and models

This research employs a dataset consisting of annual secondary data from 1991 to 2020 for MENA countries, which include Lebanon, Algeria, Jordan, Egypt, Bahrain, Iran, Tunisia, Morocco, Iraq, Turkey, Libya, Kuwait, Qatar, Oman, Saudi Arabia, Syria, Yemen, and the United Arab Emirates. Data was collected from the World Bank Development Indicators (WDI), Energy Information Association (EIA), and Global Footprint Network (GFN). Fig. 1 and Fig. 2 show the CO2 emissions[2] and total energy consumption, based on the Global Energy Statistics, from 1991 until 2020 for the MENA region, displaying a rising trend. The time period used in this study was determined based on data availability, from 1992 to 2020.[3] Moreover, Libya and Yemen were excluded from the study due to insufficient data.

The study's dependent variable is environmental degradation (ED), which is measured in several ways. Besides carbon dioxide emissions measured using two proxies, which only contribute to a minor extent to environmental damage, two other measures are also employed, namely ecological footprint and greenhouse gas emissions. These environmental indicators selected for this study—CO2 emissions (CO2), ecological footprint (EF), and greenhouse gas emissions (GHE)—were chosen due to their comprehensive representation of environmental degradation. CO2 emissions are a widely used measure of industrial pollution and are particularly relevant in the context of the MENA region's heavy reliance on fossil fuels. The ecological footprint provides a holistic view of human impact on natural resources, encompassing various environmental aspects such as land and water use. Greenhouse gas emissions offer an additional layer of understanding of the region's contribution to global warming. These indicators collectively capture the multifaceted nature of environmental degradation in the MENA region.

[2] CO2 emissions only cover coal, oil and gas as fossil fuels combustion. They are calculated based on UNFCCC methodology (in line with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories).

[3] Ecological Footprint data is only available until 2018.

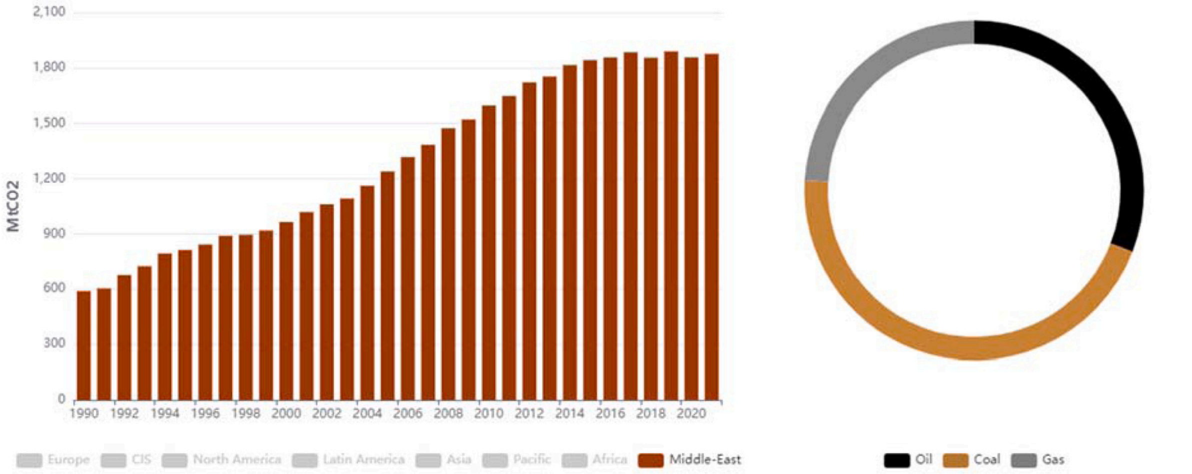

Fig. 1. CO2 Emission.

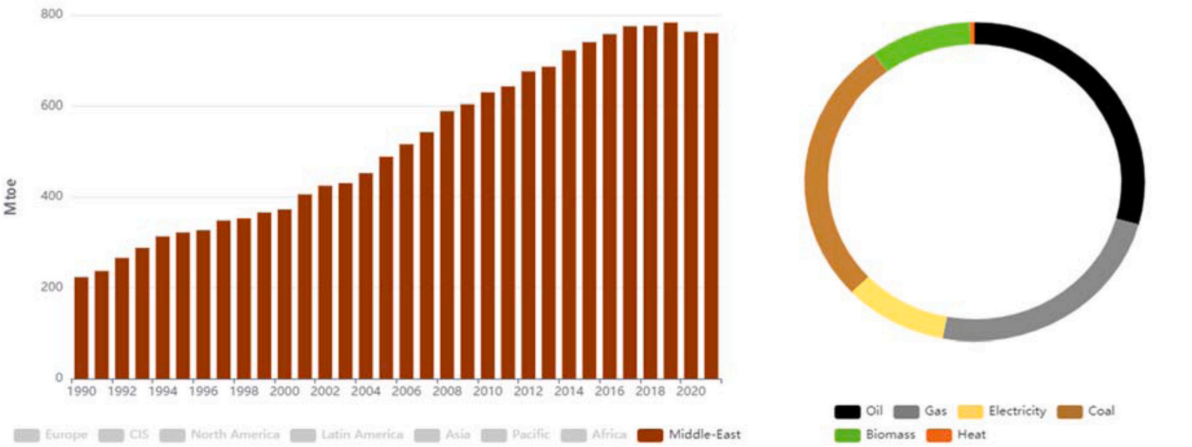

Fig. 2. Total energy consumption.

1. CO2 emissions (CO2): measured as the amount of carbon dioxide emissions (CO2) resulting from various activities such as burning fossil fuels (solid, liquid, and gas), gas flaring, and cement production, from World Development Indicator.
2. Ecological footprint (EF): measuring the impact of human activities on the natural environment, expressed in terms of the amount of land and water required to sustain those activities and absorb the waste and pollution they generate. It encompasses cropland, build-up land, grazing land, fishing ground, forest land, and carbon footprint. EF is used to determine the total land and water required to produce the resources consumed by individuals, populations, or activities and dispose of the waste and pollution generated. It indicates how human activities relate to the planet's ecosystems and their capacity for renewal and is commonly used as an indicator of environmental degradation in literature (Pata, 2018).
3. Greenhouse Gas emissions (GHE): measuring six main items, namely CO2 emissions, methane, sulphur hexafluoride, nitrous oxide, hydrofluorocarbons, and perfluorocarbons.
4. Carbon emissions 2 (CE): gathered from the Energy Information Administration (EIA) and are utilized to compare findings with traditional CO2 emissions.

To understand the factors influencing environmental degradation, several explanatory variables have been employed, including economic growth (GDP), renewable energy (REN), nonrenewable energy (NREN), resource rent (RENT), technological innovation (INV), urbanization (URB), in addition to foreign direct investment net inflows (FDI) and gross capital formation (CAP). The selection of variables in this study was based on both theoretical frameworks and empirical evidence. Economic growth (GDP) was chosen due to its widely recognized impact on environmental degradation, as postulated by the Environmental Kuznets Curve (EKC) hypothesis. Renewable and non-renewable energy consumption were included to differentiate their distinct effects on environmental outcomes, supported by studies such as (Wang et al., 2018). Natural resource rents were considered to understand the role of resource dependency, following the ecological modernization and treadmill of production theories. Technological innovation was included to capture advancements in environmentally friendly technologies, consistent with findings by (Kostakis, 2024). Urbanization, FDI, and gross capital formation were selected based on their significant roles in economic and environmental dynamics, as highlighted in previous research by (Al-Mulali and Ozturk, 2015).

$$CO2_{it} = \vartheta_0 + \vartheta_1 GDP_{it} + \vartheta_2 GDP^2_{it} + \vartheta_3 REN_{it} + \vartheta_4 NREN_{it} + \vartheta_5 RENT_{it} + \vartheta_6 INV_{it} + \vartheta_7 URB_{it} + \vartheta_8 FDI_{it} + \vartheta_9 CAP_{it} + \varepsilon_{it} \tag{1}$$

$$EF_{it} = \vartheta_0 + \vartheta_1 GDP_{it} + \vartheta_2 GDP^2_{it} + \vartheta_3 REN_{it} + \vartheta_4 NREN_{it} + \vartheta_5 RENT_{it} + \vartheta_6 INV_{it} + \vartheta_7 URB_{it} + \vartheta_8 FDI_{it} + \vartheta_9 CAP_{it} + \varepsilon_{it} \tag{2}$$

$$GHE_{it} = \vartheta_0 + \vartheta_1 GDP_{it} + \vartheta_2 GDP^2_{it} + \vartheta_3 REN_{it} + \vartheta_4 NREN_{it} + \vartheta_5 RENT_{it} + \vartheta_6 INV_{it} + \vartheta_7 URB_{it} + \vartheta_8 FDI_{it} + \vartheta_9 CAP_{it} + \varepsilon_{it} \tag{3}$$

$$CE_{it} = \vartheta_0 + \vartheta_1 GDP_{it} + \vartheta_2 GDP^2_{it} + \vartheta_3 REN_{it} + \vartheta_4 NREN_{it} + \vartheta_5 RENT_{it} + \vartheta_6 INV_{it} + \vartheta_7 URB_{it} + \vartheta_8 FDI_{it} + \vartheta_9 CAP_{it} + \varepsilon_{it} \tag{4}$$

- **Gross Domestic Product (GDP) per capita**: Measured in constant 2010 USD, GDP per capita is used as a proxy for economic growth, following (Wang et al., 2018). It reflects the total economic output, representing changes in the production of goods and services. Economic growth is often seen as both a primary cause of environmental degradation and a potential solution to environmental problems. Studies have shown that economic growth is linked to increases in CO2 emissions and the ecological footprint (EF), both indicators of environmental degradation. Therefore, it is expected that economic growth will have a positive impact, as indicated by the coefficient parameter $\vartheta 1$, while its square will have a negative impact according to the EKC hypothesis. The positive value of this parameter can also support the pollution haven hypothesis.

  In addition to examining aggregate GDP, we disaggregate economic growth into sectoral components—industrial, manufacturing, agricultural, and service contributions to GDP—allowing us to assess the distinct environmental impacts of each sector. This disaggregated approach provides a more granular understanding of the drivers of environmental degradation.
- **Renewable energy consumption (REN):** Refers to energy that is derived from natural sources that are replenished and do not get depleted with use, such as sunlight, wind, water, rain, geothermal heat, waves, biomass, and tides. These sources are considered renewable because they are not finite like fossil fuels and can be naturally replenished relatively quickly. Renewable energy is considered a clean, abundant, and sustainable alternative to conventional sources of energy, with the potential to mitigate environmental pollution compared to traditional fossil fuels. These findings are supported by studies conducted by (Wang et al., 2018). Therefore, it is expected that REN will positively contribute to the environment, reducing ED (negative coefficient parameter $\vartheta 3$). Total renewable energy consumption, including nuclear, renewables, and other sources, is measured in metric tons of oil equivalent and is obtained from the Energy Information Administration (EIA).
- **Nonrenewable energy consumption (NREN):** Refers to energy extracted from finite and unsustainable sources, such as coal, natural gas, and other liquids. It is measured in metric tons of oil equivalent from the EIA. NREN significantly contributes to environmental pollution. It is expected that NREN will increase pollution, with a positive impact on ED, as represented by the coefficient parameter $\vartheta 4$.
- **Resource rent (RENT):** Represents the total natural resource rents as a percentage of GDP, including oil rents, forest rents, mineral rents, coal rents, and natural gas rents, as defined by (Nathaniel and Khan, 2020). There are mixed findings about the effect of RENT. The coefficient $\vartheta 5$ can be positive according to some theories while negative according to others. It is positive under the ecological modernization and treadmill of production theories, and negative under the endogenous growth theory.
- **Technological Innovation (INV)**: Defined as the total number of resident and non-resident patent applications. Innovations in renewable energy and the invention of environmentally friendly vehicles can reduce pollution and emissions related to energy consumption and transportation. Technological innovations include advancements in renewable energy technologies (e.g., solar, wind, and geothermal energy systems), energy-efficient industrial processes, and the development of green transportation solutions. These innovations are particularly relevant to the MENA region, where transitioning from fossil fuels to renewable energy sources is critical for reducing environmental degradation. For instance, large-scale solar power projects, such as the Shams Solar Power Plant in the UAE, exemplify how technological innovation can significantly impact environmental outcomes by reducing CO2 emissions and ecological footprints. Therefore, it is expected that technological innovation will reduce environmental degradation, with a negative impact represented by the coefficient parameter $\vartheta 6$.
- **Urbanization (URB):** Measured as the percentage of the population living in urban areas. It is expected to have a significant impact on environmental degradation (positive $\vartheta 7$).
- **FDI inflows**: Defined as inward direct investment to the domestic economy made by foreigners. Using the same theories explaining economic growth and environmental quality, studies suggest that FDI can have a mixed impact on carbon emissions and the ecological footprint. The effect of FDI diverges under scale and composition effects. The former can lead to pollution, waste, and ecological degradation, while the latter leads to a structural shift toward more polluting industries. In the case of technological spillover, FDI could reduce environmental degradation. Therefore, the coefficient $\vartheta 8$ can be positive in the case of the pollution haven hypothesis and negative in the case of the pollution halo hypothesis.
- **Gross capital formation (CAP)**: Measured as the share of real GDP. Its impact on environmental quality is mixed. This study theorizes a positive association between capital formation and ED unless an increase in fixed capital formation takes the form of technological innovation.

Overall, this study provides valuable insights into the complex interactions between economic and environmental factors and their impact on the environment. The variables used in this research are further detailed in Table 1, including their measures, symbols, predicted signs, and economic explanations.

To reduce nonnormality and heteroscedasticity and to ensure that the data series have constant variance, all variables were converted to the natural logarithm.

3.2. Econometric analysis and techniques

Our methodology involves five main steps to ensure robust analysis. First, we conduct a cross-sectional dependency test using the (Pesaran, 2004) method due to the cross-country nature of our data. This test is crucial for identifying any cross-sectional dependencies that could bias our results. Second, we assess the heterogeneity of slope coefficients across the cross-section using the (Pesaran and Yamagata, 2008) slope heterogeneity test, which allows us to account for variations in the impact of our variables across different countries. Third, we test the stationarity properties of the specified variables using the cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented Im, Pesaran, and Shin (CIPS) tests. These tests are essential for ensuring that our time series data do not exhibit unit roots, which could lead to spurious regression results. Fourth, we test for the equilibrium relationship among the variables using the (Westerlund, 2005) panel cointegration test, confirming whether a long-run equilibrium relationship exists among our variables. Fifth, we employ the augmented mean group (AMG) method (Eberhardt, 2012) to determine the impact of variables on environmental degradation. Unlike traditional methods such as Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), AMG can handle cross-sectional dependence and heterogeneity among countries effectively, accounting for unobserved common factors that may affect all cross-sections, providing more reliable and unbiased estimates. Furthermore, AMG allows for heterogeneous slope coefficients, accommodating the possibility that the impact of explanatory variables may differ across countries. This flexibility is crucial for our analysis given the diverse economic and environmental contexts of the MENA countries in our sample. The AMG method's robustness to various forms of model misspecification and its ability to produce consistent estimates in the presence of cross-sectional dependence makes it a superior choice for our study. Eberhardt (2012) demonstrated that the AMG approach effectively mitigates biases associated with cross-sectional dependence and slope heterogeneity, making it particularly suitable for our study's dataset. These five steps are explained below.

Step 1: Cross-sectional Dependency Test

Given the cross-country nature of our data, it is essential to test for cross-sectional dependence (CD) to ensure the accuracy and efficiency of our results. Traditional econometric methods often overlook CD, leading to potential biases. Furthermore, determining the presence of CD is critical because many advanced tests, such as the Westerlund cointegration test and Cross-Sectionally Augmented IPS (CIPS), assume that there is dependence between the different sections. Hence, it is necessary to test cross-sectional dependence to to choose the appropriate estimator that guarantees stability and precision (Nathaniel and Khan, 2020). Following (Charfeddine and Kahia, 2019), the study applies Pesaran CD, which detects cross-sectional dependence within panel data. The CD test utilized is based on (Pesaran, 2004), and is represented by equation (5) below:

$$CD = \sqrt{2 \Big/ N(N-1) \quad (\sum_{i=1}^{N-1} \sum\nolimits_{j=i+1}^{N} \sqrt{t_{ij} \quad \rho_{ij}}}$$

where ρ_{ij} represents the correlation coefficient between the residuals of different cross-sectional units. T and N represent the time and cross-sectional dimensions of the panel. If cross-sectional dependence (CD) is present, the alternative hypothesis must be accepted.

Step 2: Slope Homogeneity Test

To account for differences in social, economic, and demographic structures across countries, we determine whether the slope coefficients are consistent across the panel data. We use the (Pesaran and Yamagata, 2008) slope heterogeneity test, which is superior to traditional tests as it accounts for CD (Khan et al., 2020). Identifying slope heterogeneity is crucial for selecting an appropriate estimation method that accurately reflects the diverse impacts of explanatory variables across countries.

Step 3: Unit Root Test

Testing the stationarity of variables is vital to avoid spurious regression results. We employ second-generation tests like the Cross-

Table 1
Variables Description.

Variables (Symbol)	Units	Source	Sign
CO2 Emissions (CO2)	Kt of CO2	WDI	
Ecological Footprint (EF)	Global Hectares per capita	GFN (Global Footprint Network)	
Greenhouse Gas Emissions (GHE)	Kt of CO2	WDI	
Carbon Emissions (CE)		EIA	
Gross Domestic Product per Capita (GDP)	Per capita Constant 2010 US$ or in US	WDI	Positive
Renewable Energy Consumption (REN)	Renewable energy consumption in Quadrillion Btu	EIA	Negative
Non-Renewable Energy Consumption (NREN)	Nonrenewable energy consumption in Quadrillion Btu	EIA	Positive
Natural Resource Rent (RENT)	Percentage of GDP	WDI	Negative/Positive
Technological Innovation (INV)	Patent Applications	WDI	Negative
Urbanization (URB)	Percentage of the total population	WDI	Negative/ Positive
Foreign Direct Investment	Percentage of	WDI	Positive
Gross capital formation (CAP)	Percentage of GDP	WDI	Positive

sectionally Augmented Im, Pesaran, and Shin (CIPS) (Pesaran, 2015) and Cross-sectionally Augmented Dickey-Fuller (CADF) tests to check the stationarity of the specified variables. Ensuring stationarity confirms that our time series data do not exhibit unit roots, which is necessary for the validity of subsequent analyses.

Step 4: Cointegration using Westerlund

We apply the (Westerlund, 2005) panel cointegration test to determine the long-term equilibrium relationship among the variables. This test is more effective than traditional cointegration tests as it is suitable for models with slope heterogeneity. It examines the null hypothesis of no cointegration by assuming that the error correction term in a conditional error correction specification of the panel is zero. This step ensures that our variables have a long-run equilibrium relationship, which is crucial for meaningful interpretation of the results.

Step 5: Augmented Mean Group Analysis

Economists have suggested different techniques for analyzing panel data. However, prior studies have utilized first-generation methods such as Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), which can produce inconsistent and biased results. To address issues such as cross-sectional dependence, slope heterogeneity, and endogeneity, we employ the augmented mean group (AMG) method (Eberhardt, 2012). This method can tackle various problems, including cross-sectional dependence, slope heterogeneity, and endogeneity. Moreover, it offers the benefit of providing country-specific estimates that could assist in policymaking for individual countries.

In summary, our econometric models are based on several critical assumptions: (1) Cross-sectional Dependence detected using the Pesaran (2004) CD test, addressing potential biases from dependencies among cross-sections; (2) (and slope Heterogeneity assessed with the Pesaran and Yamagata (2008) test, allowing for variations in the impact of explanatory variables across countries; (3) Stationarity, confirmed using CADF and CIPS tests, ensuring that our time series data do not exhibit unit roots; and (4) Cointegration, verified using the Westerlund (2005) panel cointegration test, establishing a long-term equilibrium relationship among variables. By meticulously applying these methodological steps and validating these key assumptions, we aim to provide a rigorous and comprehensive analysis of the factors influencing environmental degradation in the MENA region.

4. Results

Table 2 presents a summary of statistics that are crucial in evaluating the variables' central tendency and spread. The findings reveal that CO2 ranges from a minimum of 8.857 Kt to a maximum of 13.365 Kt, while EF has an average of 17.371 ha per capita, with a span of 15.446–19.401.

The correlation matrix between the variables is shown in Table 3. The first four variables are highly correlated since they are proxies for the dependent variable. RENT, REN, and NREN are positively correlated with CO2, EF, GHE, and CE, while URB and FDI are negatively correlated with these four variables. High correlations exceeding the accepted rule of thumb are observed between NREN and CO2, EF, GHE, and CE. For the other pairs, there is no issue of multicollinearity, as none of the correlation coefficients surpass the general guideline of 0.8.

Panel data estimation can be influenced by unobserved and global common shocks, or cross-sectional dependency. Given the increasing interconnectedness of the global economy, the impact of shocks (such as changes in oil prices and global financial crises) in one country can ripple through to others. Ignoring the possibility of cross-section dependence can lead to a flawed, biased, and unreliable model. Therefore, this research examines cross-section dependence (CSD) using the methods developed by (Pesaran, 2004). Table 4 shows that the cross-section dependence null hypothesis has been rejected (p-value 0.000). The range of the correlation coefficient, from 0.087 to 0.808, indicates a strong relationship between cross-sectional units. Consequently, second-generation tests must be conducted to account for the cross-sectional dependence between nations.

Similarly, it is unwise to assume a uniform slope coefficient without confirming the presence of heterogeneity, as this could lead to incorrect estimations. Therefore, we used the Slope Homogeneity Test to evaluate the heterogeneity of slope coefficients across the cross-section. The results show a significant value (Table 5), which rejects the null hypothesis of homogeneous slope coefficients. Consequently, enforcing homogeneity restrictions on the findings derived from the panel data could lead to biased or uncertain results. Hence, to achieve precise estimates, we must employ second-generation unit root and cointegration approaches.

Table 2
Descriptive Statistics (Log variables).

Variable	Mean	Std. Dev.	Min	Max
CO2	11.057	1.061	8.857	13.365
EF	17.371	.984	15.446	19.401
GHE	11.454	1.072	9.087	13.738
CE	4.151	1.102	2.104	6.497
GDP	8.817	1.113	6.589	11.028
RENT	1.729	2.671	−6.852	4.2
REN	−3.115	2.398	−6.908	0
NREN	.02	1.143	−2.172	2.507
URB	4.259	.228	3.753	4.605
FDI	.122	1.938	−13.121	3.514
CAP	3.193	.347	1.436	4.083

Table 3
Correlation Analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) CO2	1.000									
(2) EF	0.929	1.000								
(3) GHE	0.994	0.922	1.000							
(4) CE	0.990	0.902	0.981	1.000						
(5) GDP	0.070	-0.214	0.032	0.153	1.000					
(6) RENT	0.537	0.340	0.576	0.549	0.305	1.000				
(7) REN	0.314	0.151	0.308	0.358	0.463	0.441	1.000			
(8) NREN	0.985	0.884	0.978	0.996	0.191	0.586	0.375	1.000		
(9) URB	-0.232	-0.460	-0.271	-0.174	0.722	-0.097	0.084	-0.156	1.000	
(10) FDI	−0.233	−0.155	−0.268	−0.212	0.053	−0.266	−0.165	−0.215	0.132	1.000
(11) CAP	0.151	0.237	0.152	0.133	−0.161	−0.069	−0.164	0.142	0.015	0.013

Table 4
CSD.

Variable	CD-Test	P-value	Correlation
CO2	37.94	0.000***	0.752
EF	39.22	0.000***	0.808
GHE	36.78	0.000***	0.729
CE	36.59	0.000***	0.712
GDP	14.93	0.000***	0.291
RENT	24.93	0.000***	0.490
REN	13.84	0.000***	0.269
NREN	37.78	0.000***	0.735
FDI	12.17	0.000***	0.275
URB	36.13	0.000***	0.703
CAP	3.91	0.000***	0.087

Table 5
Slope Homogeneity Test.

Variable	Model 1 (CO2)	Model 2 (EF)	Model 3 (GHE)	Model 4 (CE)
Delta	9.241 (0.000***)	7.492 (0.000***)	11.161 (0.000***)	3.509 (0.000***)
Adjusted	11.603 (0.000***)	9.572 (0.000***)	14.014 (0.000***)	4.368 (0.000***)

Table 6
Unit Root Tests.

Variable	CADF Level	CADF First Difference	CIPS Level	CIPS First Difference	Order
CO2	−2.306*	−11.296***	−2.368**		I(0)
EF	−3.038***				I(0)
GHE	−2.336*	−11.212***	−2.376**		I(1)
CE	−2.857***		−2.511***		I(0)
GDP	−1.115	−3.818***	−2.059	−3.818***	I(1)
RENT	−4.006***				I(0)
REN	−3.870***		−2.773***		I(0)
NREN	−2.389***		−2.389**		I(0)
FDI	−6.139***		−3.712***		I(0)
URB	−0.483	−1.573*	−1.895	−2.178*	I(1)
CAP	1.960	−9.797***	1.935	−3.678***	I(1)

Notes: ***p $<$ 0.01, **p $<$ 0.05, and * p $<$ 0.1

Spurious regression can affect the econometric analysis, so performing a stationarity test helps avoid such issues. Table 6 reports the CADF and CIPS tests at level and first difference, which are more reliable in detecting non-stationarity in the presence of cross-sectional dependence (CD) and heterogeneous variables. The results reveal that all variables, except GDP and CAP, are stationary. Therefore, we conclude that all the series have a mixed order of integration, allowing for the application of (Westerlund, 2005) cointegration methods.

The results of the Westerlund cointegration test, based on two statistics, are shown in Table 7. The null hypothesis of no cointegration is rejected according to our first statistic, except for Model 4. This indicates the existence of cointegration between ED and the aforementioned variables. However, the second statistic does not reject the null hypothesis, confirming that while some panels are cointegrated, not all panels exhibit cointegration.

Initially, we use in all our models the same independent variables while for the dependent variable, we propose four proxies: CO2 emissions, ecological footprint, greenhouse gas emissions, and CO2 emissions from EIA to explore the factors influencing environmental degradation (ED). The independent variables are GDP per capita, renewable energy, non-renewable energy, natural resources rent, foreign direct investment, urbanization, and gross capital formation. Since innovation data is unavailable for all countries across all years, each model is estimated twice, with and without innovation. Additionally, because renewable energy is insignificant in most MENA regions, Table 9 runs the same analysis, substituting REN with renewable energy as a percentage of total energy. It is crucial to note that the share and size of renewable energy consumption may not have the same impact on ED. If the increase in renewable energy consumption size is not accompanied by a reduction in conventional fossil fuel usage, the percentage of renewable energy in total energy consumption may decrease, resulting in an increase in CO2 emissions rather than a decrease.

Table 8 demonstrates a positive and significant GDP coefficient in Models 2 and 3, indicating that economic growth positively affects the ecological footprint and greenhouse gas emissions, consistent with the scale effect and in agreement with (Ahmed et al., 2020). However, this outcome is undesirable from a theoretical standpoint since an increase in income leads to more economic activities, including natural resource extraction and industrialization, ultimately resulting in environmental degradation. Moreover, higher income induces greater human consumption and production activities that require more water and land, resulting in a larger ecological footprint. The quadratic term of GDP is insignificant in all models, which is inconsistent with the EKC hypothesis. (Danish et al., 2019) discovered that economic expansion in the BRICS nations had a substantial negative impact on the environment, with greater GDP levels linked to higher CO2 emissions and larger ecological footprints. This is consistent with the Environmental Kuznets Curve (EKC) theory, which postulates that environmental degradation results from early economic expansion and then improves with increasing income levels. Additionally, (Wang et al., 2017) highlight the relationship between GDP and the ecological footprint, emphasizing that higher levels of economic activity have a greater influence on the environment. They place a strong emphasis on how energy use mediates this relationship. On the other hand, (Nathaniel and Khan, 2020) show a complex link in which GDP development initially causes a rise in the ecological footprint, but that impact can eventually be lessened by regulatory actions and technology advancements. This suggests that environmental degradation cannot be accurately predicted by GDP alone.

Second, Tables 8 and 9 show that the impact of natural resource rent on indicators of environmental degradation is inconsistent, with a favorable effect on EF but no discernible effect on carbon and greenhouse gas emissions. This is due to the extraction or use of natural resources in an unsustainable manner, which may be a result of inadequate resource management systems and have detrimental effects on the economy and the environment. The beneficial effect on EF is in line with earlier studies from China (Ahmed et al., 2020), which find that environmental degradation results from the use of natural resources. Nevertheless, it runs counter to research from the BRICS and EU (Balsalobre-Lorente et al., 2022) that suggests natural resources can help slow the acceleration of the EF. The increased demand for energy and materials puts immense pressure on natural resource reserves, leading to environmental stress. Although natural resources can enable countries to use renewable energy sources and reduce fossil fuel imports, this is not the case for MENA countries, whose reliance on renewable energy is still minimal. The study's conclusions are consistent with earlier research showing that environmental degradation results from emerging nations' high fossil fuel consumption (Destek and Aslan, 2017). Given that fossil fuels have a greater negative impact on the sustainability of the environment, policymakers must develop energy policies that lessen reliance on conventional energy sources and technologies.

Third, the study's findings show that there is no conclusive link between the use of renewable energy and any indicators of environmental deterioration. Renewable energy is predicted to reduce ecological footprint and CO2 emissions, but in our models, this effect is not statistically significant. This may be due to the lower use of renewable energy in production, including service and industrial sectors. However, Table 9 demonstrates that when renewable energy is expressed as a percentage of all energy, it significantly increases CO2 emissions, suggesting that renewable energy can help slow down environmental deterioration. This bolsters the notion

Table 7
Westerlund Cointegration.

Statistic	Model 1 (CO2)	Model 2 (EF)	Model 3 (GHE)	Model 4 (CE)
Variance Ratio[a]	−1.6332 (0.0512*)	−1.9724 (0.0243**)	−1.3669 (0.0858*)	−1.2693 (0.1022)
Variance Ratio[b]	−0.8101 (0.2090)	−0.9099 (0.1814)	−0.6759 (0.2495)	−1.2049 (0.1141)

Notes: The alternative hypothesis is some panels are cointegrated in a versus all panels are cointegrated in b.
***p < 0.01, **p < 0.05, and * p < 0.

Table 8
AMG Estimation.

Variable	CO2		EF		GHE		CE	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
GDP	0.145 (0.385)	0.194 (0.109)	**0.347 (0.017)****	−0.040 (0.883)	0.161 (0.194)	**0.284 (0.037**)**	−0.024 (0.839)	0.015 (0.914)
GDP^2	−0.011 (0.659)	0.021 (0.519)	0.030 (0.497)	−0.056 (0.670)	−0.011 (0.540)	0.019 (0.830)	0.003 (0.937)	−0.006 (0.873)
RENT	−0.000 (0.996)	−0.021 (0.178)	0.026 (0.174)	0.034 (0.340)	−0.003 (0.790)	−0.013 (0.173)	**0.017 (0.010**)**	−0.003 (0.785)
REN	−0.003 (0.490)	−0.004 (0.679)	−0.004 (0.539)	−0.012 (0.658)	−0.000 (0.959)	−0.006 (0.333)	0.010 (0.146)	0.012 (0.445)
NREN	**0.478 (0.000***)**	**0.385 (0.000***)**	**0.383 (0.000***)**	**0.502 (0.000***)**	**0.399 (0.000***)**	**0.225 (0.006***)**	**0.850 (0.000***)**	**0.766 (0.000***)**
FDI	−0.002 (0.649)	**−0.007 (0.031)****	**−0.013 (0.086*)**	**−0.020 (0.036**)**	−0.003 (0.475)	**−0.008 (0.000***)**	**0.007 (0.077*)**	0.005 (0.575)
URB	3.324 (0.228)	0.640 (0.394)	−1.273 (0.263)	−1.526 (0.590)	0.747 (0.433)	0.937 (0.333)	0.252 (0.725)	0.823 (0.112)
CAP	**0.063 (0.087*)**	0.073 (0.103)	**0.157 (0.003***)**	0.216 (0.112)	**0.058 (0.030**)**	**0.073 (0.083*)**	−0.042 (0.276)	−0.017 (0.918)
INV		−0.013 (0.410)		0.017 (0.674)		−0.008 (0.496)		0.022 (0.106)
Constant	−0.358 (0.963)	**7.327 (0.000)*****	**21.242 (0.003)*****	**26.001 (0.024**)**	**6.885 (0.019**)**	**6.201 (0.001)*****	2.531 (0.316)	0.487 (0.779)

that creating renewable energy sources is crucial for achieving the world's climate goals. The coefficients for the share of renewable energy consumption are consistently larger than those of the total amount of renewable energy consumption in the four models used in the study, indicating that the share of renewable energy consumption has a greater effect on ED than the total consumption. As a result, the proportion of renewable energy consumption is a better indicator for this research. In conclusion, the use of renewable energy in the MENA countries is insufficient for reducing the negative effects of human activity on the environment and achieving sustainability.

Fourth, using non-renewable energy sources harms the environment and affects all environmental degradation indicators. This is not surprising considering that the fossil fuels used to produce these energy sources are the main contributors to greenhouse gas emissions. Because they are limited and unsustainable, nonrenewable energy sources exacerbate climate change and global warming by raising greenhouse gas emissions. Therefore, promoting energy-efficient technologies is advised for MENA nations in order to improve energy efficiency, lower CO2 emissions, and lessen environmental impact.

Fifth, the findings indicate that FDI has a detrimental effect on CO2 emissions as well as GHE (model b), EF (models a and b), and CE (model a). Thus, we prove that the "halo" hypothesis holds and multinational corporations from developed nations can teach local businesses in MENA nations advanced environmental knowledge and techniques. As a result, when foreign businesses invest in MENA nations, they bring with them knowledge, technology, and business strategies that can boost the productivity and competitiveness of local businesses operating in the same sector. Environmentally friendly technologies are facilitated by FDI. Our findings run counter to

Table 9
AMG Estimation Using Renewable Energy Percentage.

Variable	CO2		EF		GHE		CE	
	(a)	(b)	(a)	(b)	(a)	(b)		
GDP	0.221 (0.153)	0.175 (0.468)	**0.461 (0.000)*****	0.191 (0.534)	**0.218 (0.074*)**	−0.035 (0.403)	0.082 (0.462)	0.119 (0.234)
GDP^2	−0.002 (0.963)	−0.019 (0.560)	0.062 (0.424)	−0.047 (0.657)	−0.006 (0.810)	−0.005 (0.815)	−0.033 (0.237)	−0.008 (0.846)
RENT	−0.015 (0.221)	**−0.029 (0.005***)**	0.031 (0.198)	0.078 (0.109)	−0.012 (0.145)	−0.010 (0.202)	0.010 (0.549)	0.002 (0.708)
REN%	**−0.037 (0.000***)**	−0.047 (0.104)	0.015 (0.510)	0.111 (0.269)	−0.019 (0.140)	−0.018 (0.181)	−0.034 (0.197)	**−0.042 (0.001***)**
NREN	**0.462 (0.000***)**	**0.254 (0.034**)**	**0.303 (0.032**)**	**0.403 (0.000***)**	**0.335 (0.000***)**	**0.171 (0.047**)**	**0.856 (0.000***)**	**0.728 (0.000***)**
FDI	0.001 (0.762)	**−0.005 (0.041)****	**−0.010 (0.054*)**	−0.006 (0.621)	−0.003 (0.441)	**−0.006 (0.000***)**	0.002 (0.682)	0.005 (0.657)
URB	0.222 (0.863)	**0.991 (0.066*)**	−0.565 (0.646)	−0.454 (0.836)	0.565 (0.336)	0.650 (0.133)	−0.295 (0.736)	**0.662 (0.095*)**
CAP	**0.072 (0.075*)**	0.089 (0.188)	**0.160 (0.016**)**	0.165 (0.359)	**0.093 (0.014**)**	**0.084 (0.026**)**	−0.041 (0.394)	−0.021 (0.813)
INV		−0.019 (0.134)		−0.002 (0.923)		−0.011 (0.258)		0.013 (0.400)
Constant	8.017 (0.135)	**6.298 (0.000)*****	**14.394 (0.004)*****	**17.405 (0.067*)**	**4.604 (0.000***)**	**7.832 (0.000)*****	**5.136 (0.051)***	0.257 (0.863)

the "pollution haven" theory, which contends that foreign direct investment (FDI) causes host countries' pollution levels to rise.

Sixth, except in Table 9 where CO2 emissions are the dependent variable, urbanization is not statistically significant. Although at 10 %, its positive impact indicates that there is a trade-off between environmental sustainability and economic growth. Urbanization-induced economic growth results in higher levels of energy consumption, transportation, and industrial activity, all of which increase CO2 emissions. Additionally, urbanization leads to greater economies of scale and resource efficiency, which can reduce ecological footprints in some areas, such as water and land use.

Seventh, gross capital formation has a favorable effect on environmental degradation, showing that capital formation and emissions in G7 nations are inversely correlated. These findings imply that these nations' capital formation is not environmentally friendly, and that they should make investments in more environmentally friendly technologies to support a low-carbon economy.

Our findings align with and extend the existing literature on the environmental impacts of economic activities and technological advancements. For instance, the significant reduction in environmental degradation through renewable energy consumption is consistent with studies by (Paramati et al., 2017). However, our results also highlight discrepancies, such as the non-significant impact of technological innovation on CO2 emissions, which contrasts with findings by (Kostakis, 2024). These differences may stem from regional variations in the implementation and effectiveness of technological advancements, underscoring the need for context-specific analyses.

Finally, Table 8 shows that there is no significant relationship between technological advancements and environmental quality. Although technological innovations are essential for sustainable development in emerging economies and can support low carbon emissions and energy efficiency, as demonstrated in OECD and EU countries (Cho and Sohn, 2018), our results are contradictory.

To complement our analysis and determine whether the composition effect prevails, Table 10 presents regressions using CO2 emissions, EF, and GHE as the dependent variables. Instead of GDP, we use four variables: industrial contribution to GDP (IND), manufacturing contribution to GDP (MANF), agricultural contribution to GDP (AGR), and services contribution to GDP (SERV). Other explanatory variables include natural resource rent, renewable energy (measured in units in Model c and as a percentage of total energy in Model d), non-renewable energy, FDI, urbanization, and CAP. Our results show that MANF and AGR positively impact EF, while MANF negatively affects GHE. The results of this study highlight the substantial impact of the manufacturing sector on environmental degradation in the MENA region, as evidenced by its significant contribution to the ecological footprint. This finding is consistent with previous research that identifies manufacturing activities as key drivers of environmental stress, particularly in developing and resource-rich economies. The high ecological footprint associated with the manufacturing sector can be attributed to the intensive use of natural resources, energy consumption, and waste generation that characterize industrial processes (Ulucak et al., 2020). The lower greenhouse gas emissions linked to the manufacturing sector, while seemingly paradoxical, may be explained by variations in emissions accounting methodologies or the reliance on less carbon-intensive processes within the region's industrial sectors. However, the overall environmental impact remains significant due to the broader ecological degradation associated with land and water use, resource extraction, and pollution. The agricultural sector's positive impact on the ecological footprint underscores the need for more sustainable agricultural practices in the MENA region. Agriculture, particularly when characterized by inefficient water usage, deforestation, and land degradation, contributes significantly to environmental degradation. This sector's environmental

Table 10
AMG Estimation with Subsectors.

Variable	CO2	EF	GHE	Variable		
	(c)	(d)	(c)	(d)	(c)	(d)
IND	−0.003	−0.039	−0.266	−0.187	0.175	0.055
	(0.984)	(0.844)	(0.499)	(0.723)	(0.414)	(0.795)
MANF	−0.064	−0.115	0.136	**0.338**	−0.063	**−0.157**
	(0.335)	(0.142)	(0.320)	**(0.065*)**	(0.370)	**(0.094*)**
AGR	−0.063	−0.032	**0.155**	**0.074**	−0.003	0.027
	(0.248)	(0.683)	**(0.022*)**	**(0.025**)**	(0.995)	(0.697)
SERV	0.121	0.063	0.392	0.402	0.150	0.030
	(0.525)	(0.797)	(0.135)	(0.129)	(0.290)	(0.892)
RENT	0.001	0.015	−0.004	0.018	−0.012	0.004
	(0.886)	(0.165)	(0.818)	(0.328)	(0.565)	(0.671)
REN	−0.005		−0.005		−0.005	
	(0.247)		(0.486)		(0.201)	
REN%		−0.022		0.018		−0.020
		(0.257)		(0.591)		(0.14)
NREN	**0.448**	**0.405**	**0.301**	**0.174**	**0.382**	**0.350**
	(0.000*)**	**(0.000***)**	**(0.027**)**	**(0.066*)**	**(0.000***)**	**(0.000***)**
FDI	−0.001	−0.000	−0.012	**−0.005**	−0.004 (0.247)	−0.002
	(0.0671)	(0.915)	(0.101)	**(0.003***)**		(0.473)
URB	**1.643**	**1.434**	0.015	−1.614	**2.582**	**1.635**
	(0.093*)	**(0.000***)**	(0.991)	(0.557)	**(0.012)****	**(0.075*)**
CAP	**0.043**	**0.048**	**0.120**	**0.178**	0.037	0.041
	(0.030)**	**(0.072*)**	**(0.027**)**	**(0.000***)**	(0.157)	(0.218)
Constant	2.765	**0.662**	**15.542**	**19.664**	−2.261	2.093
	(0.590)	**(0.007***)**	**(0.000***)**	**(0.018**)**	(0.740)	(0.711)

impact is compounded by the region's arid climate, which places additional strain on water resources and leads to soil erosion and desertification.

The causality analysis, following (Dumitrescu and Hurlin, 2012), is conducted after the regression analysis. According to the findings of the DH Granger causality test, shown in Table 11, economic growth, nonrenewable energy, and resource rent are causally related to CO2 and GHE in MENA. Additionally, the empirical findings reveal a two-way causal connection between ED and economic growth, as well as between ED and NREN. These findings indicate that any policy intended to lower ED, GDP, or NREN will have an equal and opposite effect.

5. Conclusion

This study builds on existing research regarding the variables influencing environmental degradation in MENA nations from 1991 to 2020. The data were sourced from the Global Footprint Network, Energy Information Association, and World Bank Development Indicators. Indicators of environmental degradation included CO2 emissions, the ecological footprint, and greenhouse gas emissions. Explanatory variables comprised economic growth, renewable and non-renewable energy, resource rent, technological innovation, urbanization, foreign direct investment, and gross capital formation. Using the AMG estimation method, the results indicated that technological advancement and renewable energy consumption negatively impact environmental degradation, whereas economic growth and non-renewable energy consumption have a significant positive impact. These findings can inform policy decisions on sustainable development in MENA countries and contribute to ongoing global efforts to combat environmental degradation.

This study's findings have several key implications. Firstly, economic growth alone does not suffice to reduce ecological footprints and greenhouse gas emissions. Policies solely focusing on growth may harm the environment. The insignificance of GDP squared suggests that increased income alone won't improve environmental quality, contradicting the EKC theory. Thus, implementing environmental management, regulations, and incentives for green technologies is essential. Policymakers must balance economic growth with environmental protection to achieve sustainable development goals. Secondly, natural resource rent shows a mixed impact, positively affecting the ecological footprint but not significantly impacting greenhouse gas and carbon emissions. This indicates a need for revised natural resource management policies to ensure sustainable resource use and minimize environmental degradation. MENA nations should shift resources from resource-rich sectors to manufacturing to benefit from natural resource rents while ensuring sustainability and growth. Thirdly, renewable energy has no significant impact on environmental degradation in absolute terms but significantly reduces CO2 emissions when part of total energy consumption. This underscores the importance of adopting renewable energy technologies for sustainable development. Fourthly, excessive use of nonrenewable energy sources degrades the environment across all indicators. MENA countries should invest in energy-efficient technologies and reduce reliance on nonrenewable energy to enhance energy efficiency. Fifthly, the relationship between gross capital formation and environmental degradation suggests that policies promoting long-term investments are necessary to balance economic growth and environmental protection. Sixthly, the weak link between technological advancements and environmental quality implies that mere technological progress isn't enough for sustainability. Policymakers should promote environmentally friendly technologies and consider factors like energy efficiency, renewable energy adoption, and natural resource management. Taxes on fossil fuels and policies supporting green technologies are crucial for sustainable development. Finally, sectoral composition plays a role in environmental degradation in MENA economies, with the manufacturing sector contributing most to a higher ecological footprint but lower greenhouse gas emissions. The agricultural sector also increases the ecological footprint. Policymakers should focus on targeted interventions for these sectors to mitigate their environmental impact. A differentiated policy approach is essential. In the manufacturing sector, policies should emphasize the adoption of cleaner production technologies, energy efficiency improvements, and waste reduction strategies. For the agricultural sector, sustainable practices such as water-efficient irrigation, conservation tillage, and the promotion of agroecological farming methods are essential to reducing the ecological footprint. Given the region's dependency on both sectors for economic growth, these strategies must balance environmental goals with economic development needs, ensuring that sustainability does not come at the expense of economic viability.

The presence of the halo hypothesis has significant implications for MENA nations. These countries often rely heavily on natural resource exports, have limited economic diversification, and a fragile private sector. FDI can help overcome these challenges by attracting capital, transferring technology, and developing local industries. However, the benefits of FDI vary based on factors such as local institutional development, the business environment, and the integration of foreign and domestic firms. MENA countries should implement policies that foster linkages between international and local businesses, such as tax incentives, streamlined regulations, and investments in education and training. This can help leverage the FDI halo effect for economic development. Additionally, the fact that urbanization reduces CO2 emissions but has little effect on the ecological footprint highlights the need for balanced development strategies that consider both economic and environmental sustainability. Sustainable urbanization should be supported by policies promoting renewable energy, public transportation, eco-friendly infrastructure, and sustainable urban design.

Given that capital formation and economic growth increase CO2 emissions, greenhouse gases, and ecological footprint, MENA countries cannot achieve sustainable economies by prioritizing economic benefits alone. Governments must focus on boosting economic growth while enhancing environmental quality. Effective environmental regulations and innovative approaches are essential for fostering greener business strategies and creating a solid institutional framework for the long-term growth of national economies.

However, the study has some limitations and presents guidelines for future research. Firstly, the study only covers the economic systems of MENA countries, and future studies should expand their scope to other emerging countries. Secondly, the role of institutional quality in promoting sustainable resource utilization in emerging economies should be investigated in future studies. Third, the socio-economic diversity within the MENA region poses unique challenges and opportunities for the generalizability of our findings.

Table 11
Dumitrescu-Hurlin Panel Causality Tests.

Null Hypothesis	Z-bar	Prob	Conclusion
GDP => CO2	5.6993	0.000***	GDP⇔CO2
CO2 => GDP	7.7099	0.000***	
RENT => CO2	6.3983	0.000***	RENT => CO2
CO2 => RENT	0.2258	0.8214	
REN => CO2	0.8307	0.4062	CO2 => REN
CO2 => REN	1.7920	0.0731*	
NREN=> CO2	7.1371	0.000***	NREN⇔ CO2
CO2=> NREN	6.6001	0.000***	
GHE			
GDP=> GHE	5.2842	0.000***	GDP⇔GHE
GHE=> GDP	11.1267	0.000***	
RENT=> GHE	5.6974	0.000***	RENT => GHE
GHE=> RENT	−0.0736	0.9414	
REN=> GHE	0.7827	0.4338	GHE => REN
GHE=> REN	10.1208	0.000***	
NREN=> GHE	5.1607	0.000***	NREN⇔ GHE
GHE=> NREN	6.6830	0.000***	

Notes: ***$p < 0.01$, **$p < 0.05$, and * $p < 0$.

Variations in policy effectiveness, resource availability, and technological adoption rates across countries can influence the impact of renewable energy and technological innovations. For example, countries like the UAE and Saudi Arabia, with substantial financial resources and governmental support, are more likely to implement successful renewable energy projects compared to countries with less economic stability. This diversity suggests that while our findings provide valuable insights, tailored strategies considering each country's context are necessary for effective policy implementation. Finally, the limitations of the AMG estimation method should be acknowledged. Although AMG is suitable for handling cross-sectional dependence and heterogeneity, it may have limitations in capturing complex dynamic relationships. Exploring alternative estimation methods could provide a more comprehensive understanding.

For future research, several specific areas warrant further investigation. First, exploring the long-term impacts of technological innovations and renewable energy adoption in diverse socio-economic contexts within the MENA region is vital to provide insights into developing reliable and relevant environmental regulations. Second, the role of institutional quality in promoting sustainable resource utilization in emerging economies should be explored, as strong institutions may enhance the effectiveness of environmental policies. Third, expanding the scope to include other emerging economies could help generalize the findings and develop a more comprehensive understanding of the global dynamics of environmental sustainability. Fourth, longitudinal studies on the long-term impacts of FDI, considering the differences between these investments based on the investment type and sector, on environmental sustainability would provide valuable insights for strategic planning. Lastly, investigating the effectiveness of specific environmental regulations and green technologies in reducing ecological footprints and greenhouse gas emissions would contribute to more targeted and impactful policy recommendations.

CRediT authorship contribution statement

Anna Min DU: Writing – review & editing, Validation, Supervision, Project administration, Investigation, Conceptualization. **Rim El Khoury:** Writing – original draft, Resources, Investigation, Conceptualization. **Hazem Marashdeh:** Formal analysis, Data curation. **Nohade Nasrallah:** Writing – original draft, Software, Methodology, Data curation. **Osama F Atayah:** Methodology, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Data Availability

Data will be made available on request.

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