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# Impact of Renewable Energy, Trade Openness, and Oil Prices Considering the Role of Human Capital on the Environment: A Case Study of MENA Countries

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**Abstract:** Environmental pollution and climate change have been recognised as serious problems in the world, with the MENA (Middle East and North Africa) regions being no exception in facing one of the major challenges. Considering the detrimental impact of these problems on the ecological environment, countries have to find feasible measures to reduce pollutant emissions and improve environmental quality. In this context, renewable energy, trade openness, oil prices, and human capital may be causes of enhancing environmental quality. This paper investigates the effect of renewables, trade openness, oil prices, and human capital on environmental quality (CO2 emissions and ecological footprint) in 19 MENA countries between 2010 and 2023. We used the NARDL approach for this estimation. The findings reveal that renewable energy consumption and trade openness have a positive effect on the decline in CO2 emissions and ecological footprint, and increasing oil prices have a negative effect on environmental quality. Human capital also serves as a significant factor that can have a positive impact on environmental quality through this variable. The study thus verifies the hypothesis based on the results above i.e., these factors substantially improve the environmental quality in MENA. Accordingly, it is suggested by policymakers in the MENA region invest more in renewable energy sources, foster the trade of goods, utilize the management of oil price to its benefit, and develop human capital for the environmental and clean energy sectors to enhance the environmental quality and sustainable development within the region.

**Keywords: Renewable energy, trade openness, oil prices, human capital, environment.**

**INTRODUCTION**: The release of greenhouse gases remains one of the world's largest contributors to climate change. Carbon dioxide, the most prevalent greenhouse gas, is at the heart of this reaction. Carbon dioxide emitted from human industrial activities and the combustion of fossil fuels has been reported to account for approximately 78% of the world's general GHG emissions from 1970 to 2023 (IPCC, 2024). In this context, carbon dioxide gas emissions, as a main cause of climate change, have been the focus of environmental policies across the globe (Kim et al., 2019).

In the Middle East and North Africa (MENA) region, for which there are also oil-exporting countries, including Iran and Iraq, cutting carbon emissions is especially problematic. The region is faced with significant environmental challenges in the form of its reliance on oil exports and fossil fuel consumption. In reaction to this, MENA countries have begun to invest in renewable desert power as a means of curbing carbon emissions and improving environmental standards. But the percentage of RE in the energy basket of these nations is said to be far less. So, for example, in 2022, renewable energy made up just 2.5% of Iran's total energy generation. Iraq has also begun to invest in solar and wind energy in the last few years, but these attempts have yet to produce a substantial dent in carbon emissions (British Petroleum, 2023).

Trade openness, renewable energy, and oil prices are important environmental determinants in these countries. In both Iran and Iraq, the focus of international trade is on the export of crude oil on the one hand, and the import of consumer goods on the other. As a result, heavy reliance on oil exports and the importation of industrial and consumer goods can result in significant environmental impacts. On the other hand, its expansion may improve environmental quality through the transfer of green technologies and the increase of investments in environmental infrastructure (Omari et al., 2024).

When assessing environmental impacts, the H factor should not be isolated. Human capital endowments, such as education, workforce skills, and environmental awareness, may also play a critical role in carbon abatement and environmental quality improvement. While faced with structural difficulties, human capital potential in MENA is also considerable. Other research evidence has shown that enhancing education and skills enhancement can lead to enhanced energy utilization with more green technology (Sadooi & Omri, 2023).

The purpose of this paper is to examine the influence of renewable energy, trade openness, and oil prices on environmental quality in MENA states, with a specific emphasis on human capital. Several important novelties are reported for the first time in this work. Firstly, this study seems to be the first of its kind to investigate the asymmetric effects of renewable energy, oil prices and trade openness on the environment, considering on the role of human capital in MENA countries. In fact, the approach not only includes CO 2 emissions but also the ecological footprint index, resulting in a more complete measure of environmental quality. Lastly, quantitative regression analysis (NARDL) is employed to investigate both the positive and negative effects of the changes in the explanatory variables, hence, obtaining a better understanding of the associations between them.

## 1. Theoretical Foundations and Research Background

This section explores the impact of renewable energy, trade openness, economic growth, oil prices, and human capital on environmental degradation, focusing on carbon dioxide emissions and the ecological footprint. The literature review is structured into five parts, beginning with an analysis of the relationship between renewable energy technologies and environmental degradation.

### 2-1. **Impact of Renewable Energy on Environmental Degradation**

There are several mechanisms that justify the link between renewable energy and environmental degradation and elucidate how such sources can be both beneficial and harmful to the environment. Most importantly, switching to renewables including solar, wind and hydro power, means the reduction of dependence on fossil fuels, and a decrease of carbon pollutants as well as greenhouse gases. These changes, particularly the reduction of carbon dioxide emissions, have a positive impact and are contributing to taming global warming. By providing an alternative to non-renewable resources, especially fossil fuels, the reliance on such energy sources and the environmental impacts related to resource extraction, fossil fuel pollution and climate change can be lessened. For sustainable development theories: renewable energy can be linked to sustainable development goals, which are toward improving the environmental quality and mitigating the negative impact of economic business on the ecosystem.

In economic theory, and particularly in sustainable growth and environmental economics literature, the utilization of renewable resources represents a solution to counterbalance the environmental effects of human activities. The clean lines thesis, sometimes mentioned in the studies, also states that the countries that are successful in utilizing renewable resources can ensure their economic growing without serious harm to the environment. In the environmental models, renewable energy is free of charge and is put as an instrument to fill the green gap between economic expansion and environmental degradation. As such, policy measures designed to raise the proportion of renewable energy in the energy blend of a country can generate environmental gain and decrease the extent of environmental destruction (Omari et al., 2024).

In this regard, the association between the usage of renewable energy and environmental quality is a commonly studied area, where the empirical findings of the studies are mostly inconsistent (Anwar et al., 2021; Azam et al., 2021; Pata and Koglar, 2021; Salari et al., 2021). However, the dominant opinion is that, when certain policies are in place, alternative energy can help decrease environmental degradation. Therefore, the consumption of renewable energy has a positive effect on the environmental quality and carbon dioxide emission and ecological footprint decrease because of that.

With the enormous potential for the generation of renewable energy in this region, the insertion of clean technologies is highly important. Recent works from some African countries have confirmed that renewable energy has positive direct and indirect effect on enhancing environmental quality. For example, research conducted by Joestick et al. (2024) also showed that renewable energy use in Ghana between 1990 and 2020 led to the reduction of carbon dioxide emissions. Kwakwa (2023), moreover, suggested that the economic growth of Africa's industry and agriculture increased environmental pollution, but the application of renewable energy sources could reduce it somewhat.

In ASEAN countries, Anwar et al. (2021) explored the impact of renewable energy and fossil fuels on environmental quality in terms of quantiles. Their findings indicated that the use of renewable energy was negatively correlated with pollution emissions. Other studies in developed countries like the USA have also reported the presence of similar factors (Salari et al., 2021; Shahbaz et al., 2017). Furthermore, Erdogan et al. (2023) focused on the contribution of renewable energy technologies to the CO2 mitigation from oil sources in the G7 countries.

In European populations, disparate findings have been reported. For example, Markus et al. In a study in France, Boucekkine et al. (2016) prove that the renewable energy does not bring out a major contribution in reducing CO2 emissions, and the growth in CO2 emission has spurred the development of renewable energy. Contrary to this upregulatory effect, Alola et al. (2019) indicated the impact of renewable energy on carbon emissions for the leading European economies. It was also in recent years that the carbon footprint has been treated as an outcome restricted to the greenhouse effect, while the ecological footprint as a general measure of environmental pressure. Li et al. (2023) found that renewable energy is a significant factor in mitigating the ecological footprint for low-, middle-, and high-income countries. Similarly, Osman et al. (2020) and Raza et al. (2023) substantiated lower ecological footprints by the usage of clean energy in the U.S. and G20 members. Research directed at emerging economies and MENA countries, such as Sekib et al. (2023) and Youlah et al. (2021), have provided that there is a significant negative effect on the ecological footprint level due to the use of green energy.

In Iran, Mahoudi (2024) carriedout research on the role of energy storage and renewable utilization in environment preservation, and his research findings show that renewable resources can contribute to the global objectives in environmental. Karami et al. (2023) while investigating building renovation and energy optimization concluded that the utilization of renewable energy sources in the renovation system may lead to a reduction of greenhouse gas emissions. Hosseini (2022) discussed the effect of renewable and non-renewable energy consumption on economic growth and the environment and found a reduction in carbon dioxide emissions through renewable energy consumption in oil-rich countries. Mahmoud et al. (2021) studied the role of renewable energy in alleviating environmental pollution in Iran and concluded that policy to elevate the share of renewable energy in the country’s energy matrix would reduce pollutions and conserve vital natural resources.

2-2. **Impact of Trade Openness on Environmental Degradation**

Trade openness is regarded as a crucial variable influencing economic and environmental progress. In terms of effects on environmental pollution, three main mechanisms may result in such a relationship: (1) enhancing the access to clean and modern technologies through international trade. Countries with open trade can access cleaner technologies and production methods that potentially lower the release of pollutants and greenhouse gases. This access to cleaner technologies has been particularly meaningful in the energy sector and in industrial processes where countries can import cleaner machinery and cleaner technologies. It strains credulity for conservatives and neoliberal market apologists to argue the opposite, i.e., that more cutthroat open global competition is an inducement to increased energy efficiency and pollution control. In such circumstances, businesses and nations will strive to decrease production costs and enhance product quality; the reduction in the use of resources and emissions of pollutants is a possibility as well.

But some perverse mechanisms may scale up environmental losses. One of these mechanisms is the relocation of pollutant industries from the industrialised to the developing countries. The opening of trade borders also causes that, and results in the shifting of some high-polluting industries to the low environmental standard-based countries and that demand higher level of energy consumption from those low-environmental standard-based countries, thus increasing the rate of environmental degradation in those countries (Omari et al., 2024). Hence, the proposal has been made that trade openness enhances environmental quality and helps decrease CO2 emissions as well as the ecological footprint.

The effect of trade openness on the quality of the environment Many studies have analyzed the effect of trade openness on the quality of the environment based on three effects: technique, composition, and scale. However, previous studies had already reached different results on the relationship between trade, different environmental degradation indicators and especially carbon dioxide emissions (Fang et al., 2020; Pata & Koglar, 2021). Studies by Ali et al..XRLabel, 2019, Godar et al., 2019, have shown that trade helps mitigate CO 2 and carbon emissions whilst others find trade exacerbates CO 2 emissions, as such Kadjo and Bart (2020), Kellenberg, 2009. (2017) and Liu and Zhou (2019), which show a positive impact of trade on CO 2 emissions. In Sub-Saharan Africa, Achampong et al. (2019) supported the positive effect of trade on CO2 emissions. Other research like Du et al. (2020) and expressed that the effect of trade on emissions hinges on a country's income. Trade can enhance environmental performance, especially in high-income countries. Yet, recent research, such as Magazzino (2024), and Liu et al. (2022), have found the positive effect of trade in and diminishing the ecological footprint in the countries such as China and Pakistan. Additionally, Alola et al. (2019) concluded that trade openness negatively affects the ecological footprint in EU member countries.

In Iran, Mohammadi et al. (2024) indicated that trade openness has various implications for the environmental quality of countries in the Middle East. It is found that trade openness may serve as a mechanism to alleviate environmental degradation and to make the dirty industries flow to the developing countries. This study stressed the significance of intelligent trade policies and environmental laws. Kazemi et al. (2023) the effect of free trade on the pollution level in developing nations was studied. Then it is reported that for some Middle Eastern countries, trade-openness increased natural resource consumption and pollution, while for others trade-open countries were able to import cleaner technologies which decreased pollutants. Additionally, Hosseini et al. (2022) studied the effect of trade policies and trade liberalization on the environment in Iran and its counterparts. Findings of these studies were that trade opened pollution to deteriorate in the short period however in the long period improvement in reduction of energy and importation of modern technologies led to negative impact.

**2-3. Impact of oil prices on environmental degradation**

How oil prices affect environmental damage is a multi-dimensional topic related to economics and ecology systems. In such a case, fluctuations in oil prices have the potential of exerting both direct and indirect effects on environmental quality. From an economic theory point of view, an increase in the price of oil is generally expected to translate into higher production costs for non-renewable energy and, consequently, a decrease in the consumption of fossil fuel and the pollution arising from it. By contrast, fluctuations in oil prices can turn the trend in the development and use of renewable energy toward the positive direction, favourable to the environment (Raza et al., 2023).

In this context, models, in particular the Environmental Kuznets Curve (EKC) hypothesis, have explored the nonlinear relationship between economic development and environmental quality. In this model, initially, when oil prices increase and the consumption of fossil fuel is increasing, pollution and environmental degradation aggravate. But in the long run, such an increase in price could stimulate the development of clean technology and enhance environmental quality. Intriguingly, the impact of oil-price changes may vary by country, particularly those that are net exporters of oil. In oil-exporting countries, the higher oil prices are associated with these economic booms, energy consumption increases emissions and accelerates local environmental degradation. Conversely, in oil-importing countries, rising oil prices may raise costs and subdue economic growth, which in turn might be detrimental to environmental quality. Because of such mechanisms, it may be hypothesized that the effect of oil prices on the environment degradation is complex in several interactions among energy supply and demand, economic growth, policies for the environment, and energy technology (Omri et al., 2022).

Many studies have investigated the effect of oil prices on economic activities (Blaid & Abd al-Rahmani, 2013; Manshah et al., 2019), however, the analysis of how oil prices influence carbon dioxide emissions has been overlooked. Some studies have argued that the impact of oil prices is crucial contingent on the type of country analyzed and whether this country is an exporter or importer of oil. Oil exporting countries Oil producers rely on oil exports to make money, and so higher oil prices generally also lead to more revenue and economic activity. On the other hand in net oil-importing economies increasing oil prices impose cost and pose a big challenge to the economy (Nasir et al., 2018).

Agbanik et al. (2019) in Venezuela, another one of the major oil producers. They found that rising crude oil prices lead to a rise in energy consumption with significant impact, while energy consumption and government expenditures lead to an increase in CO2 emissions. Boufatih (2019) investigated the nonlinear influence of oil prices on pollution for US and China. In contrast to the U.S., increasing oil prices in China did little to lower carbon emissions. Moreover, Apurgis and Gangopadhyay (2020) tackled an oil-producing country (Vietnam) and showed that an oil prices rise had not a long-lasting effect on pollution.

Hassan and Moulanga (2023) established that the environmental impact positively increases in African petrol-producing nations due to increase in the prices of oil, and vice versa in case of oil shocks. Similarly, Jouf et al. (2023) (based on the sources of energy) showed in China that with symmetric and asymmetric methods, it is established that increase in oil prices reduces ecological footprint and reduction in oil prices, increase it.

In Iran, Darvishi et al. (2024) studied the effect of oil prices on environmental pollution in oil producing countries. They found that oil price increases induce higher production and consumption of oil, which is associated with more emissions to the environment. Yousefi et al. (2023) have studied the link between oil price variations and environmental quality in the case of oil importing nations. The result shows that high oil prices enhance energy cost and reduce GDP in these countries, leading to environmental quality reduction. Additionally, Mahmoodi et al. (2022) explored the effect of fluctuations in oil price on environmental degradation in the Middle Eastern region and found that fluctuation in oil price affected the trend of energy resource use and that in some oil-producing countries, increased oil prices had improved the environment through the promotion of renewable energy.

**2-4. Impact of renewable energy, trade openness, and oil prices concerning the role of human capital on the environment**

Environmental concerns are no longer simple in the diverse world that we live in. Within these it discusses renewable energy, trade openness, oil prices and human capital. Said variables are directly or indirectly related to the environment.

In this regard, the integration of renewable energy is considered as one of the main strategies to counterbalance the adverse environmental effects of economic activities. Many evidences were presented in literature several matters what increases the portion of renewable energy in producing electric energy from a country, more the pollutants and emitting gases were decreased (Wang et al., 2024). Therefore, many works have been carried out to prove that the construction of renewable energy power generation enhances the decline in CO2 emission and the environmental quality in the process of development in developed countries (Cheng et al., 2019). An example is the work done by Yasin et al. (2024) on five BRICS nations discovered that increased use of renewable energy had a positive effect on CO 2 emissions and ecological footprints. In such countries, renewable energies are considered a means of reducing dependence on fossil fuels and the negative environmental impacts which result from their use.

Trade openness is another determinant directly related to environmental impoverishment. There are also studies indicating that natural resources consumption and pollutants emission increase with rise in the volume of international trade (Pata and Kaglar, 2021). In this regard, some research, (e.g.,Shahbaz, 2017) showed that trade openness is a moderate variable. This will help developed countries decrease environmental pollution; however, it is the opposite in developing countries. Studies in the league of Achimpong et al (2019) however reveal that in some African countries trade openness has a positive impact on CO2 emissions. This is because more trade may result in increased fossil fuel production and consumption, which will increase pollution emissions.

Oil prices is also one variable that have a great impact on environmental deterioration. For oil-exporting countries in particular, a rise in the price of oil is associated with increased energy use, and thus increased emissions of greenhouse gases. Within this framework, research such as that of Nuwani (2017) in Ecuador and that of Agbanik et al. (2019) in Venezuela have indicated that the increase of oil price is associated with the insert of the country of reference within global politics as well as with the increase of energy consumption and carbon dioxide releases. It can be concluded that the increase in oil prices could harm the environment in oil-exporting countries. In oil-importing nations, though, higher oil prices lead to lower consumption of petroleum products and thus lower emissions. For instance, Malik et al (2020) in research on Pakistan found that increasing oil prices in the long-run causes a decrease in CO2 emissions. This is as countries work to wean themselves off fossil fuels and to use cleaner sources of energy.

Ultimately, human capital emerges as the most important factor common to both the environment and economic productivity. Certain research of Zhou et al. (2022) and Wang et al. (2024) have found that along with the rise of the human capital of different nations, this can provide for a better level of environmental performance. In poor countries in particular, human capital translates into better technologies and less pollution. The use of fossil fuel can give rise to adverse impacts and human capital can prevent it by educating, investing, and innovating in safe and clean technology for one side, and can improve the use of renewable energy resources for another side. In this regard, Ahmad et al (2020) find in the BRICS economies that economic growth and human capital investment play a significant role in enhancing environmental quality. According to the theoretical underpinning, we can summarize generally that renewable energy, trade openness, and oil price exert distinct effects on the environment, which are endogenized with the part of human capital.

So, it may be inferred that the environmental impacts of renewable energy consumption, trade openness, and oil price shocks are not independent, and are substantially affected by the quantity of human capital of a country. Human capital, by encouraging technological innovation, use of clean energy and awareness of the environment, can change the effect of these aspects on environmental degradation. According to these understandings, the following will be hypothesized:

H4: The impact of renewable energy, trade openness and oil prices on environmental degradation is moderated by human capital, such that the negative environmental effects and positive impacts of these variables that are diminished by higher levels of human capital.

## 2. Research Methodology

To examine the effect of macroeconomic determinants on environmental quality in the context of MENA countries, two empirical models are used on the pattern of Omari et al. (2024), Li et al. (2023) and Ali et al. (2022). They analyze how different factors, including renewable energy, trade openness, oil prices and human capital, affect CO2 emissions and their associated environmental consequences. A number of previous studies have also applied the Nonlinear Autoregressive Distributed Lag (NARDL) model to examine CO 2 and ecological footprint determinants (Wang et al., 2020, Lahani, 2023, Hassan and Mahlanga, 2023 and Apergis and Gangopadhyay, 2023). This approach is especially suitable in searching for long-term and short-term relationships and for the effects of increases and decreases in independent variables on CO2 and ecological responses. The expression of the empirical models used in this paper are established as follows:

$$lnCO_{2it} = \beta_0 + \beta_1 lnRE_{it} + \beta_2 lnTrade_{it} + \beta_3 lnGDP_{it} + \beta_4 lnOilp_{it} + \beta_5 lnH_{it} + e_{it}$$
$$lnEF_{it} = \beta_0 + \beta_1 lnRE_{it} + \beta_2 lnTrade_{it} + \beta_3 lnGDP_{it} + \beta_4 lnOilp_{it} + \beta_5 lnH_{it} + e_{it}$$

In the first model, CO2 emissions are considered as the dependent variable, while in the second model, ecological effects (EF) are treated as the dependent variable.

**Dependent variables:**
$lnCO_{2it}$= The natural logarithm of carbon dioxide emissions (measured in tons of CO2). This data is typically collected by international organizations such as the World Bank, the International Energy Agency (IEA), or the United Nations Framework Convention on Climate Change (UNFCCC).
$lnEF_{it}$= Generally calculated based on the consumption of natural resources and the production of pollutants, it is used as an indicator to determine the impact of human activities on the ecosystem. This index is usually measured in global hectares (gha).
**Independent variables:**
$lnRE_{it}$= The amount of renewable energy production in a country, including solar, wind, hydro, and biomass energy, typically measured in terawatt hours (TWh) or gigawatt hours (GWh). These data are often extracted from national energy reports or international agencies such as the International Energy Agency (IEA).
$lnTrade_{it}$ = The total value of a country's exports and imports in a year, measured as an indicator of that country's trade openness. This data is usually collected by international economic organizations such as the World Trade Organization (WTO) or the World Bank.
$lnOilp_{it}$ = Oil prices, as one of the most important economic factors, are typically reported as the price per barrel of crude oil (USD), based on the annual average. These data are usually published by international oil agencies such as the International Energy Agency (IEA) or OPEC.
$lnH_{it}$ = Human capital, usually measured by indicators such as the level of education, professional skills, and access to training. One common index for measuring this variable is the Human Development Index (HDI), published by the United Nations Development Programme (UNDP). This index is a composite of three components: income, education, and health.
$lnGDP_{it}$ = Gross Domestic Product (GDP) of a country, which refers to the total value of goods and services produced within a country in a year, used as an indicator of the country's economic size. This data is typically published by central banks or international economic institutions such as the International Monetary Fund (IMF) or the World Bank.
It is worth noting that all variables are entered logarithmically into the model. The research sample includes 19 MENA region member countries: Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Mauritania, Oman, Palestine, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, the United Arab Emirates, and Iran, over the years 2010 to 2023. The data analysis method is based on the NARDL approach. All analyses are conducted using EViews software, version 12.

**Table (1). Variables definitions**

| Variable | Definition | Calculation / Data Source |
|---|---|---|
| $lnCO_2$_it | Natural logarithm of carbon dioxide emissions | $CO_2$ emissions measured in tons per year; Source: World Bank, IEA, or UNFCCC |
| lnEF_it | Natural logarithm of ecological footprint | Index reflecting natural resource consumption and pollutant production, measured in global hectares (gha); Source: Global Footprint Network |
| lnRE_it | Natural logarithm of renewable energy consumption | Includes solar, wind, hydro, and biomass energy, measured in TWh or GWh; Source: IEA or national energy reports |
| lnTrade_it | Natural logarithm of trade openness | Total value of exports and imports per year; Source: WTO or World Bank |
| lnOilp_it | Natural logarithm of oil prices | Average annual price per barrel of crude oil (USD); Source: IEA or OPEC |
| lnH_it | Natural logarithm of human capital | Typically measured by the Human Development Index (HDI), which includes income, education, and health; Source: UNDP |
| lnGDP_it | Natural logarithm of Gross Domestic Product (GDP) | Total value of goods and services produced annually (in current or constant USD); Source: World Bank or IMF |

Initially, it is confirmed that all variables in the model are stationary. To examine the stationarity of the variables, the tests by Zivot and Andrews (1992) and Phillips and Perron (1988) are used. Then, the existence of asymmetric cointegration is examined using the FPSS test and Pesaran and colleagues (2001). After confirming stationarity and asymmetric cointegration, the NARDL model is applied to analyze long-term and short-term relationships based on positive and negative changes in the explanatory variables. The NARDL model allows us to obtain the long-term positive and negative coefficients of each explanatory variable on CO2 and ecological effects.

## 3. Data Analysis

### 4-1. Stationarity Test

To check for stationarity of the data series, we have applied the Phillips-Perron and Zivot-Andrews unit root tests. The null hypothesis in these tests is the presence of a unit root (i.e., nonstationarity). The findings of this studies were shown in Table 1.

**Table (1). Results of the stationarity test for the variables.**

| variables | Phillips-Perron test | | Zivot-Andrews test | |
|---|---|---|---|---|
| | level | differential | level | differential |
| lnCO2 | 3.037* | 6.920* | 5.092* | 9.550* |
| lnEF | 1.709 | 9.427* | 3.255 | 10.186* |
| lnOilp | 0.980 | 6.324* | 3.617 | 7.197* |
| lnTrade | 0.403 | 5.397* | 4.400 | 5.962* |
| lnGDP | 2.119 | 6.890* | 2.958 | 7.408* |
| lnRE | 9.311 | 5.951* | 0.514 | 4.84*** |
| lnHCI | 0.850 | 7.350* | 0.452 | 6.755* |

Note: *, **, *** indicate the rejection of the null hypothesis of a unit root at significance levels of 1%, 5%, and 10%, respectively.

## Source: Research findings.

The Phillips-Perron test indicates that all variables are I(1) except for CO2 is I(0). As this test does not allow for structural breaks, we also apply the Zivot-Andrew’s test and find the variables either stationary at level or first difference and no I(2). This provides a reason for applying the NARDL model in examining the short-run and long-run connections and considering the asymmetries in the exogenous variables.

**4-2. NARDL Results**

This section is devoted to the investigation and estimation of the short-run parametric structure of the models. The objective behind estimating short-term coefficients in economic models is to investigate the immediate and early influence of some of the key variables on the environmental indicators such as CO 2 emissions and environmental degradation (EF). These are the weights from the relationship and the effect of changes to renewable energy, oil prices, trade and human capital to the targets. Short-term analyses could contribute to understanding how policies and economic actions develop in the short run and help to make timely, efficient decisions about environmental management. Short run impart of NARDL model is shown below.

**Table (2). Estimation of Short-Run NARDL Model for MENA Countries 2010-2023.**

| variable | CO2 model coefficient | t-statistic of the CO2 model | significance level of the CO2 model | FE model coefficient | t-statistic of the FE model | significance level of the FE model |
|---|---|---|---|---|---|---|
| ΔlnRE+ | 0.089*** | 1.75 | 0.012 | 0.758 | 0.031 | 0.015 |
| ΔlnRE- | 0.002 | 0.03 | 0.976 | 0.867 | 0.018 | 0.078 |
| ΔlnGDP+ | 0.056 | 0.09 | 0.933 | 1.499** | 2.44 | 0.024 |
| ΔlnGDP- | 0.141 | 0.22 | 0.825 | 0.398 | 0.71 | 0.483 |
| ΔlnOilp+ | 0.006 | 0.13 | 0.898 | 1.13 | 0.272 | 0.215 |
| ΔlnOilp- | 0.079 | 1.26 | 0.223 | 0.42 | 0.676 | 0.126 |
| ΔlnTrade+ | 0.296 | 1.06 | 0.303 | 1.73 | 0.099 | 0.245 |
| ΔlnTrade- | 0.636** | 2.19 | 0.042 | 1.78 | 0.090 | 0.245 |
| ΔlnH+ | 0.213* | 2.12 | 0.042 | 1.054 | 3.26 | 0.003 |
| ΔlnH- | 0.154- | 1.76 | 0.071 | -0.712 | -2.21 | 0.087 |
| intercept | 1.015*** | 2.00 | 0.062 | 2.236* | 4.83 | 0.000 |
| $R^2$ | 0.998 | | | 0.906 | | |

Source: Research findings

In the short term, renewable energy has a small but significant role in reducing $CO_2$ emissions and environmental degradation, though its effect is stronger in the long term. GDP significantly increases environmental degradation in the EF model, aligning with theories linking growth to environmental pressure, while its effect in the $CO_2$ model is insignificant. Oil price changes show no significant impact in the short term. Trade's negative effect on $CO_2$ is significant, indicating that reduced trade may help lower emissions, while other trade effects are insignificant. Human capital positively influences environmental improvement through better efficiency and green technology, though a weak negative effect is also observed in the EF model, possibly due to unsustainable behaviors. Overall, while some variables have clear short-term effects, others show mixed or weak results, highlighting the need for long-term analysis, especially regarding human capital.

To examine cointegration in panel data, the existence or non-existence of cointegration among the variables must first be assessed. For this purpose, the panel unit root test using the Fisher method (FPSS) is applied. This test is specifically designed for panel data and allows for the identification of nonlinear or asymmetric cointegration between different variables. Using this test is essential to confirm the long-term stability of relationships among the variables, so that subsequent analyses, such as cointegration models and long-term dynamics, can be conducted.

**Table (3). Results of the FPSS cointegration test.**

| model | Calculated F-statistic (FPSS) | critical statistic | significance level | adjustment speed of parameters | significance level (adjustment speed of parameters) |
|---|---|---|---|---|---|
| CO2 model | 3.409 | above the critical value | 1% | 0.589 | 5% |
| EF model | 4.012 | above the critical threshold | 1% | -1.432 | 1% |

**Source: Research findings**

According to the results presented in Table (2), the hypothesis of no asymmetric cointegration is rejected because the computed F-statistic for the CO2 model and the FPSS for the EF model exceed the critical upper bounds at the 1% significance level. Additionally, the adjustment parameters for the CO2 model and the EF model are significantly negative at the 5% and 1% levels, indicating the confirmation of the model's stability conditions. The long-term relationships of the model will now be estimated.

**Table (4). Results of the long-term NARDL model estimation for MENA countries during the years 2010-2023**

| variable | COefficient of the CO2 model | t-statistic of the CO2 model | significance level of the CO2 model | FE model coefficient | t-statistic of the FE model | significance level of the FE model |
|---|---|---|---|---|---|---|
| ECT | 0.589** | 2.21 | 0.040 | 1.432* | 4.89 | 0.000 |
| lnRE+ | 0.203* | 3.46 | 0.003 | 0.200** | 2.72 | 0.013 |
| lnRE- | 0.030 | 0.29 | 0.776 | 0.124 | 1.15 | 0.150 |
| lnGDP+ | 1.704* | 3.46 | 0.003 | 2.807* | 4.15 | 0.000 |
| lnGDP- | 2.612* | 3.08 | 0.006 | 0.772 | 0.81 | 0.413 |
| lnOilp+ | 0.076** | 2.39 | 0.028 | 0.003 | 0.12 | 0.905 |
| lnOilp- | 0.352 | 0.08 | 0.934 | 0.095** | 2.66 | 0.015 |
| lnTrade+ | 0.141*** | 1.80 | 0.088 | 0.801* | 3.29 | 0.004 |
| lnTrade- | 0.408*** | 2.03 | 0.058 | 0.023 | 0.13 | 0.899 |
| lnHS+ | 0.045*- | 3.20 | 0.003 | 0.037** | 2.50 | 0.012 |
| lnHS- | 0.125*- | 4.12 | 0.000 | 0.075** | 2.75 | 0.001 |

**Source: Research findings**

In the long term, renewable energy has a significant positive effect on reducing environmental degradation in both $CO_2$ and EF models, while its negative effect is not significant. Economic growth (GDP) increases environmental degradation in both models, with its negative component showing mixed or insignificant effects. Oil prices positively affect $CO_2$ emissions likely due to higher fossil fuel use while they help reduce environmental degradation in the EF model. Trade positively contributes to environmental improvement in both models through technology transfer, but reduced trade only significantly lowers $CO_2$ emissions. Human capital has a strong positive role in enhancing environmental quality in both models, while its negative impact is insignificant. Overall, renewable energy, trade, and human capital play key roles in environmental improvement over the long term.

To sum up, the ECT coefficient on the lnCO2 model is 0.589 and it is statistically significant with tstatistic 2.21 at the significant level of 0.040. This suggests that when there are deviations from long-term equilibrium, about 59% of short-run deviations in any given period will be corrected in the long run. This is indicative of a fast correction mechanism in the CO2 model which slowly moves the environment to a state of less distress when the environment is out of phase over the short term. In the lnEF model, the ECT coefficient is 1.432, significant at 1%, with a t-statistic of 4.89. This value is greater than the coefficient in the CO2 model, meaning in the EF model the speed of return to long-term equilibrium is 106 J.H. ter Horst et al. / MPRA Paper No in period Ahead by a period to short-term equilibrium, 143 % of the second period short-term deviations enter the long-term equilibrium. This implies that some error correction is stronger in the EF model than others, possibly changes in factors that affect environmental degradation, e.g., environmental policies, or structural shifts in economic sectors.

When comparing econometric results, long-run parameters are important for understanding a sustainable relationship between various variables. These settings become particularly relevant when one seeks to evaluate the impacts of economic variables on environmental variables (CO2 emission and EF) over long periods of time. Structural parameters are of long-run including coefficients on important variables such as renewable energy, oil prices, trade, human capital that could be used to examine and predict long-run changes in these aspects. These factors may exert direct and indirect influences on the environmental situation and analysis of their long-term effects could help the policy design and planning for sustainable development. In this chapter, we study the longer-term effects of these variables on the environment and deduce how they can give rise to new environmental trend-dynamics and their implications.

**Table (5). Results of Long-term NARDL Parameter Estimation for MENA Countries During 2010-2023**

| variable | CO2 model coefficient | t-statistic of the CO2 model | significance level of the CO2 model | FE model coefficient | t-statistic of the FE model | significance level of the FE model |
|---|---|---|---|---|---|---|
| ρ + RE | 0.345** | 4.990 | 0.038 | 0.146* | 14.7 | 0.001 |
| ρ - RE | 0.052 | 0.074 | 0.788 | 0.091 | 2.174 | 0.156 |
| ρ + GDP | 2.891* | 8.461 | 0.008 | 2.042* | 79.17 | 0.000 |
| ρ - GDP | 4.432*** | 3.068 | 0.097 | 0.562 | 0.777 | 0.388 |
| ρ + Oilp | 0.130** | 5.910 | 0.026 | 0.002 | 0.014 | 0.905 |
| ρ - Oilp | 0.007 | 0.000 | 0.935 | 0.070* | 10.4 | 0.005 |
| ρ + Trade | 0.598 | 1.513 | 0.235 | 0.583* | 21.04 | 0.000 |
| ρ - Trade | 0.693*** | 2.933 | 0.104 | 0.017 | 0.016 | 0.000 |
| ρ + H | 1.253* | 3.362 | 0.082 | 5.225* | 8.362 | 0.000 |
| ρ - H | 2.362** | 4.9695 | 0.002 | 4.362** | 5.251 | 0.002 |

Source: Research Findings

lnRE+ reduces environmental pollution in CO2 as well as in EF model as per long run anlaysis and this effect is statistically significant, but its negative effect on CO2 and EF is not significant. GDP growth and Environmental degradation Growth of the economy (lnGDP+) has a positive and significant influence on Environmental degradation both in model M1 and M2 while its negative effect is also insignificant. Oil prices have a highly positive impact in the $CO_2$ model and a highly negative impact in the EF model, showing the different effects on environmental indicators. Trade (lnTrade+) has a significantly positive coefficientin both the equations, 560 ZHANG AND WANG indicating that cleaner technology transfer does contribute to reducing environmental damage,its negative part being not significant. Human capital (lnH+) contributes significantly to improving environmental quality in both models, but its negative component (lnH−) is also significant, mainly indicating that unsustainable human capital can degrade the environment.

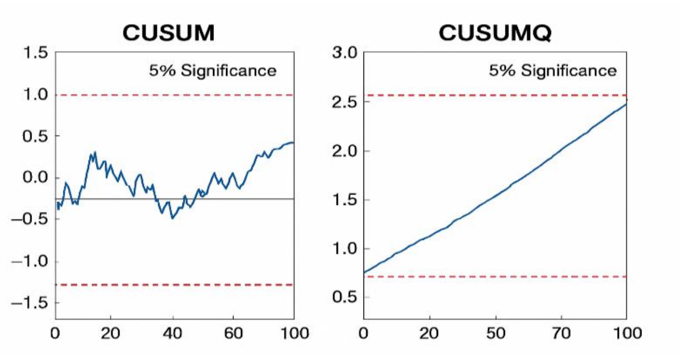
### 4-3. Results of Model Stability and Accuracy Assessment

In economic analyses and dynamic time series models, assessing the stability and accuracy of the model is of great importance. Therefore, in this section of the research, the results of diagnostic tests and model stability tests for the variables lnCO2 and lnEF, representing environmental impact indicators, are presented. These tests are used to evaluate the models employed and to confirm the accuracy and validity of the results. The results of various tests are reported in Table (6).

**Table (6). Diagnostic and Stability Test Results**

| test | lnCO2 model | lnFE model |
|---|---|---|
| Durbin-Watson | 2.433 | 2.343 |
| Breusch-Godfrey Serial Cor. LM | 1.870 (0.171) | 0.008 (0.926) |
| Heteroskedasticity (ARCH) | 5.899 (0.111) | 1.103 (0.293) |
| Ramsey RESET | 1.519 (0.250) | 0.478 (0.701) |

Source: Research Findings




**CUSUM Test for Stability of the $lnCO_2$ and lnEF Models**

The diagnostic tests confirm the validity and reliability of both the $\ln CO_2$ and lnEF models. The Durbin-Watson and Breusch-Godfrey tests show no serial correlation. The ARCH test indicates homoscedasticity, meaning constant variance. The Ramsey RESET test confirms model linearity, and both the CUSUM and CUSUMQ tests demonstrate that the models are stable over time. Overall, the models are statistically well-specified and robust.

## 5. Conclusion

The effects of renewable energy consumption, trade openness, oil prices, economic growth and human capital on environmental quality (carbon dioxide emissions and ecological footprint) in the MENA countries over the period, 2010–2023, have been investigated in this study. The short-run and long-run effects of these variables on the environmental quality were examined using NARDL model. The study findings reveal that there are short run and long run differences in the impact of these variables on environmental degradation. For a short period, we find a significant and positive relationship between renewable energy, in both the CO 2 and EF models, confirming a minor role of renewable energy on environmental degradation. These results also are consistent with environmental theories that posit that moving to renewable energy can be slow and capital intensive and also require new infrastructure. There are also GDP effects in the EF model, indicating that short run GDP growth may result in more pollution, as predicted by theories which usually associate GDP growth with elevated pollution levels. The negative influences of GDP are weak in the CO2 model, which means that GDP does not lead to the decrease of CO2 emission in the short period. Furthermore, for the CO2 model the short- run effects of oil price and trade are also important, revealing that a fall in trade results in a lower level of CO2 emissions, which is in line with economic theories which indicate that a reduction in economic activities causes lower pollutant emissions.

In the long run, the findings reveal that renewable energy significantly reduces environmental degradation, consistent with the cleaner and sustainable energy source theories that endorsed the utilization of cleaner sources of energy to reduce the level of pollution and environmental damage. The adverse effects of renewable energy are much less but not negligible, which could imply that renewable energy under low productivity situation might have a little environmental influence. Also, in the long-run GDP strongly leads to an increase in environmental degradation, which is consistent with that observed in theories of economic growth and pollution. The effect of oil prices in CO2 and the negative effect in the EF model were significant, and clearly demonstrate how oil prices may influence energy consumption patterns and environmental impacts. Because the effects of trade are statistically significant in both models, it indicates that international trade has played a role in mitigating environmental degradation by transferring green/sustainable technologies. Human capital has a positive and significant influence in both models, which proves the significance of learning, skills, and knowledge to enhance the environment.
3.7 Hypothesis Testing The empirical tests of the hypotheses concerning the direct and moderating impacts of renewable energy, trade openness, oil prices and human capital on environmental degradation were consistent. It is established that increased levels of human capital can dampen the negative effects of the environment and enhance the positive effects of other main determinants.
For the longer run, the findings suggest that renewable energy is shown to reduce environmental degradation, and this finding supports theories related to the use of clean and renewable energy sources to mitigate pollution and environmental damage. On the other hand, its negative impact is not particularly high, which may imply that in a low-productivity society, renewable energy can have limited effects on the environment. To sum up, given the lasting and positive impacts of renewable energies on curbing environmental degradation, the analysts for the best practices of both policymakers and developing countries alike are recommending further investment in clean and renewable power sources to ensure they are valued as instrumental for the preservation of the environment and pollution control. The findings also suggested that trade could act as an efficient channel in mitigating environmental deterioration. Thus, developed countries are encouraged to push their green technologies to developing countries and achieve sustainable trade through international cooperation formation. Moreover, since short-term economic growth could cause further environmental degradation, policymakers should look for measures to reduce the negative impact of economic growth on natural resources and pollution. This includes creating local policies emanating from carbon reduction and sustainable production and consumption measures. Finally, given the positive influence of human capital on environmental quality, it would be interesting to advocate for an increase in investment in environmental education and skills, especially in clean energy and natural resources management. This could strengthen the technical and scientific capability of countries in the environment and limit the negative impacts of ignorance.

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