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# The Impact of Financial Development, Foreign Direct Investment, and Trade Openness on Carbon Dioxide Emissions in Jordan: An ARDL and VECM Analysis Approach

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**Abstract:** Jordan has made substantial strides in enhancing its economy by focusing on economic growth stimulants, which include financial development, foreign direct investment (FDI), and trade openness. However, these economic activities often lead to significant environmental risks. Despite their relevance, the existing literature has rarely examined the influence of these dynamics on environmental quality in the Middle East, particularly in Jordan. This study aims to investigate the influence of financial development, FDI, and trade openness on carbon dioxide ($CO_2$) emissions in Jordan. To achieve this, the study employs the Autoregressive Distributed Lag (ARDL) technique and the Vector Error Correction Model (VECM) Granger causality approach, utilizing data sourced from the World Bank for the period from 1990 to 2022. The findings indicate that financial development, FDI, and trade openness positively impact $CO_2$ emissions, thereby increasing environmental risks in both the short and long term. Additionally, there exists a bidirectional causal relationship between financial development and both FDI and trade openness, as well as between FDI and trade openness. It is imperative for Jordan to design strategies that balance economic growth with sustainable environmental practices.

**Keywords:** financial development; FDI; trade openness; $CO_2$ emissions; Jordan

**JEL Classification:** Q52; Q53; Q56; Q57; Q58

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## 1. Introduction

Human activities, such as the exploitation of natural resources, industrialization, energy consumption, financial development, trade liberalization, foreign direct investment (FDI), transportation, construction, logistics, and infrastructure development, consistently contribute to global warming and environmental risks (Alnsour et al. 2023; Meaton and Alnsour 2012). Nevertheless, these activities are regarded as critical drivers of economic development. A substantial body of literature has indicated that the relationship between economic development and environmental sustainability remains unclear (e.g., Fakher 2019; Uddin et al. 2017).

The financial system is a crucial source of investment, facilitating access to capital and increasing both production and consumption. These activities place additional pressure on natural resources and increase the use of non-renewable energy, indicating that financial development promotes production levels and economic growth but also increases $CO_2$ emissions and negatively affects environmental quality (Shahbaz et al. 2019). However, the existing literature presents conflicting findings on the relationship between financial development and environmental quality. Several researchers (e.g., Lv and Li 2021; Kirikkaleli et al. 2022) have found that financial development reduces $CO_2$ emissions, while others have shown that it increases environmental degradation (e.g., Basheer et al. 2024; Batool et al. 2022; Anwar et al. 2022). Thus, it can be concluded that the current studies have not yet reached a reliable conclusion, indicating that the investigation of this relationship should be conducted for each country individually.

FDI is a critical instrument for transferring new technologies to host countries, contributing to the enhancement of productivity and promotion of economic growth. The relationship between FDI and environmental degradation can have either a negative or positive effect (Mahadevan and Sun 2020). The literature introduces the Pollution-Haven Hypothesis, which suggests that a lack of environmental regulations in several host countries may attract FDI but lead to environmental deterioration. Koçak and Şarkgüneşi (2018) and Sreenu (2024) found a positive relationship between FDI and $CO_2$ emissions. In contrast, the Pollution-Halo Hypothesis posits that FDI decreases $CO_2$ emissions by transferring clean technologies to host countries (Mahadevan and Sun 2020). As a result, the relationship between FDI and $CO_2$ emissions remains ambiguous and may vary across various geographical locations and temporal contexts.

Trade plays a pivotal role in promoting economic growth by leveraging competitive advantages and facilitating the transfer of resources (Ghazouani and Maktouf 2024). The exchange of goods and services results in the transfer of associated emissions across countries. The level of these emissions is influenced by technological differences in production and the emission intensities of production units (Ghazouani and Maktouf 2024). Accordingly, trade openness can have either positive or negative outcomes for the environment. For example, Omri and Saadaoui (2023) found that trade openness increases $CO_2$ emissions in 12 Middle Eastern countries. Chhabra et al. (2022) also reported similar findings in low- and middle-income countries. In contrast, Essandoh et al. (2020) and Sun et al. (2020) demonstrated that trade openness leads to a reduction in $CO_2$ emissions in sub-Saharan countries. The relationship between trade openness and environmental quality is a critical factor in the formulation of economic and environmental policies.

In summary, prior research shows contradictory findings regarding the effects of financial development, FDI inflows, and trade openness on $CO_2$ emissions. This contradiction may be attributed to variations in the econometric models employed for data analysis (Aldegheishem 2024; Al-Mulali et al. 2015; Apergis et al. 2023; Chhabra et al. 2022; Kirikkaleli et al. 2022; Ling et al. 2022). Therefore, this study addresses this gap by utilizing two techniques, the Autoregressive Distributed Lag (ARDL) technique and the Vector Error Correction Model (VECM) Granger causality approach, to examine both the long-run and short-run relationships among the variables, including an assessment of causality. Additionally, previous research has only partially integrated these dynamics to assess their effects on $CO_2$ emissions. There is also a lack of research on the economic determinants of $CO_2$ emissions in the Middle East, highlighting the need for further investigations to enhance the current literature (Shokoohi et al. 2022; Aghasafari et al. 2021; Akadiri and Akadiri 2020; Shahbaz et al. 2019). Therefore, this study aims to examine the impact of financial development, FDI inflows, and trade openness on $CO_2$ emissions in Jordan over the period from 1990 to 2022.

Jordan is currently facing significant economic challenges, including high unemployment rates, substantial external and internal debts, and slowing economic growth (Almasria et al. 2024). As a result, the country largely relies on the financial sector, FDI, and trade openness to stimulate its economy. Meanwhile, Jordan is recognized as one of the most impoverished countries globally in terms of energy and water resources. In response to these challenges, the country is actively seeking FDI and pursuing trade liberalization as strategies for economic development (Arabeyyat et al. 2024). Notably, over 95% of Jordan's energy is imported from neighboring countries (Alrwashdeh 2022). Furthermore, the majority of imported energy is non-renewable and sourced from fossil fuels, increasing $CO_2$ emissions (Sandri et al. 2020). The country's energy needs have grown at an average annual increase of 5%; however, there have been instances where this growth has exceeded 5%, as evidenced by an 8.5% increase in energy needs in 2019 compared to 2018

(Alrwashdeh 2022). Consequently, elevated energy prices, coupled with high public taxes, hinder investment opportunities and impede international trade. Nevertheless, Jordan has committed to the Paris Agreement, which aims to mitigate the risks associated with climate change by reducing carbon emissions. The country needs innovative solutions to reduce non-renewable energy consumption and decrease $CO_2$ emissions while simultaneously enhancing FDI and trade openness to improve economic growth. The empirical findings of this research may provide valuable insights for policymakers to improve environmental quality without compromising economic growth.

The remainder of this study is structured as follows: Section 2 reviews the literature review related to this study, Section 3 presents the data sources and empirical model used in this research, Section 4 presents the empirical results and discussion, and the conclusion and recommendations are provided in Section 5.

## 2. Literature Review

### *2.1. Financial Development and $CO_2$ Emissions*

The literature has extensively analyzed the relationship between financial development and environmental sustainability. A critical component in promoting economic growth is the efficiency of financial systems. Scholars argue that financial markets can stimulate economic development by attracting FDI (Frankel and Romer 2017). Birdsall and Wheeler (1993) indicate that financial development facilitates the adoption of clean technologies that reduce environmental pollution and promote the production of sustainable goods. Tamazian and Rao (2010) and Tamazian et al. (2009) illustrate that the growth of the financial sector offers many economic benefits, including increased investment opportunities, reduced borrowing costs, and enhanced energy efficiency, all of which contribute to decreasing $CO_2$ emissions. Rafique et al. (2020) observed that financial development led to a reduction in $CO_2$ emissions in the BRICS countries from 1990 to 2017. Abid et al. (2022) found a negative relationship between financial development and $CO_2$ emissions in the G8 countries—comprising the USA, UK, Germany, Italy, France, Canada, Japan, and Russia—during the period from 1990 to 2019. Usman et al. (2022) illustrated that financial development lowers $CO_2$ emissions, which has led to improved environmental quality in Pakistan from 1990 to 2017.

On the other hand, financial development may contribute to an increase in $CO_2$ emissions by stimulating production activities. Khezri et al. (2021) argue that the expansion of the financial sector leads to increased energy consumption and subsequently raising $CO_2$ emissions. Shoaib et al. (2020) revealed that financial development increased $CO_2$ emissions in both G8 and D8 countries between 1999 and 2013. Wang et al. (2020) analyzed the factors affecting $CO_2$ emissions in N-11 countries from 1990 to 2017, revealing a positive relationship between financial development and $CO_2$ emissions. Ahmad et al. (2020) examined the effect of financial development on $CO_2$ emissions in 90 Belt and Road countries during the same period, finding that financial development degrades environmental quality by increasing $CO_2$ emissions. Qayyum et al. (2021) demonstrated that financial development increased $CO_2$ emissions in India from 1980 to 2019. Ling et al. (2022) illustrated that financial development stimulated $CO_2$ emissions in China from 1980 to 2017. Additionally, Khezri et al. (2021) examined six financial growth metrics across 31 Asia-Pacific countries between 2000 and 2018, revealing a positive relationship between all six metrics and $CO_2$ emissions.

Global economic growth has significantly increased, primarily due to substantial developments in communication and transportation technologies over the past two decades. Financial development has stimulated this growth, benefiting both developed and developing countries by accelerating economic expansion, increasing financial services, and raising income levels. Nevertheless, this rapid economic growth has also led to various environmental challenges, including increased energy consumption, depletion of natural resources, and a rise in $CO_2$ emissions.

*2.2. FDI and $CO_2$ Emissions*

The relationship between FDI inflows and environmental quality remains a topic of debate. The Pollution Haven Hypothesis (PHH), initially proposed by Walter and Ugelow (1979), suggests that FDI inflows can lead to environmental degradation in host countries. In contrast, the "Pollution Halo Hypothesis", introduced by Birdsall and Wheeler (1993), posits that FDI can reduce emissions by transferring clean technologies to host countries, thereby preserving natural resources and protecting the environment (Yi et al. 2023). Both hypotheses agree that FDI inflows contribute to economic growth by promoting production and the adoption of clean technologies.

Several studies have indicated that FDI is associated with an increase in $CO_2$ emissions. For example, Javed et al. (2023) found that FDI contributed to a rise in $CO_2$ emissions in Italy during the period from 1971 to 2019. Similarly, Pata et al. (2023) illustrated that FDI is linked to elevated $CO_2$ emissions within the Association of Southeast Asian Nations from 1995 to 2018. Raihan (2024) established a positive correlation between FDI inflows and $CO_2$ emissions in Vietnam over the period from 1990 to 2021. Wencong et al. (2023) revealed a positive impact of FDI on $CO_2$ emissions in transition economies from 1998 to 2019. Additionally, Salahuddin et al. (2018) identified a positive relationship between FDI and $CO_2$ emissions in Kuwait from 1980 to 2013. Likewise, Lee (2013) observed that, while FDI enhances economic growth in 19 G20 countries, it is also associated with an increase in $CO_2$ emissions from 1971 to 2009. Essandoh et al. (2020) established a positive relationship between FDI and $CO_2$ emissions in low-income countries during the period from 1991 to 2014. Adjei-Mantey and Adams (2023) found that FDI stimulates $CO_2$ emissions in 29 sub-Saharan African countries during the period from 2001 to 2015. Abdul-Mumuni et al. (2023) reported similar findings for 41 sub-Saharan African countries over the period from 1996 to 2018. A recent study by Zheng et al. (2024) affirmed that FDI leads to an increase in $CO_2$ emissions in China, supporting the PHH in both short- and long-term scenarios.

Another body of literature has highlighted a negative relationship between FDI and $CO_2$ emissions. Apergis et al. (2023) investigated the influence of FDI on $CO_2$ emissions within BRICS countries from 1993 to 2012, finding that FDI inflows from Italy, Germany, and France into BRICS countries lead to a decrease in $CO_2$ emissions. Wang et al. (2023) found that the relationship between FDI and $CO_2$ emissions is influenced by an increase in GDP per capita, observing that an increase in GDP per capita results in a negative effect of FDI on carbon emissions. Their research demonstrated that FDI contributes to a reduction in carbon emissions in high-income countries, including the United States, Australia, Switzerland, Sweden, Iceland, Singapore, and Denmark. In a similar context, Rafindadi et al. (2018) found that FDI plays a role in decreasing $CO_2$ emissions in affluent Arab Gulf states, including Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, Bahrain, and Oman. Likewise, Abid et al. (2022) revealed a negative relationship between FDI and carbon emissions in G8 countries—comprising the UK, Germany, Italy, France, Canada, Russia, and Japan—based on time series data from 1990 to 2019. Shaari et al. (2014) reported that an increase in FDI does not correlate with an increase in $CO_2$ emissions, drawing on data from 1992 to 2012 across 15 developing nations. Furthermore, Saadaoui et al. (2024) indicated that FDI inflows lead to a reduction in $CO_2$ emissions in Turkey from 1985 to 2021.

As a result, the relationship between FDI and environmental sustainability remains a subject of ongoing scholarly debate. This discussion is based on the premise that FDI is positively correlated with economic development. Some researchers argue that when FDI is accompanied by clean technologies, it can significantly contribute to improving environmental sustainability. Additionally, the economic growth facilitated by FDI has the potential to improve living standards and alleviate poverty, which are often viewed as significant drivers of environmental degradation in many developing countries.

As a result, the influence of FDI on environmental quality varies across countries, influenced by the income levels of these countries and the types of technologies used in production processes. Such variations can be attributed to differences in environmental regulations and the degree of economic openness within each country.

### 2.3. Trade Openness and $CO_2$ Emissions

The literature on the relationship between trade openness and $CO_2$ emissions provides contradictory findings. Some studies suggest that trade openness has a positive effect on $CO_2$ emissions, thereby increasing environmental degradation. For instance, Chhabra et al. (2022) conducted an empirical investigation focusing on the BRICS countries from 1991 to 2019, demonstrating that trade openness significantly contributes to environmental degradation. Similarly, Omri and Saadaoui (2023) identified a bidirectional causal relationship between trade and emissions in France during the period from 1980 to 2020. Ibrahim et al. (2024) found a positive impact of trade openness on $CO_2$ emissions in Germany, utilizing time series data from 1990 to 2020. Jiang and Liu (2023) examined the influence of trade openness on carbon emissions by comparing the BRICS (Brazil, Russia, India, China, and South Africa) and G7 (USA, UK, Germany, France, Italy, Japan, and Canada) countries from 1992 to 2019. Their study revealed that trade openness fosters growth in carbon emissions in BRICS nations while restricting growth in G7 countries. Suhrab et al. (2023) demonstrated that trade openness leads to an increase in $CO_2$ emissions in Pakistan, based on time series data from 1985 to 2018. Akhayere et al. (2023) observed a negative impact of trade openness on environmental quality in Turkey by analyzing data from 1965 to 2018. Aldegheishem (2024) identified a positive relationship between trade openness and $CO_2$ emissions in Saudi Arabia through an examination of annual time series data from 1991 to 2023. Finally, Wang et al. (2024) highlighted the role of trade openness in stimulating carbon emissions in G20 nations between 1997 and 2019.

Contrary to the above assumptions, a substantial body of research has demonstrated that trade openness can have a negative impact on $CO_2$ emissions, thereby improving environmental quality. For example, Thi et al. (2023) found that trade openness contributes to a decrease in carbon emissions across 53 countries from 1990 to 2019. Similarly, Hasanov et al. (2021) analyzed the effects of exports and imports on $CO_2$ emissions in nine major exporting nations, revealing an inverse relationship between exports, imports, and $CO_2$ emissions. Furthermore, Sohag et al. (2017) investigated the impact of trade openness on $CO_2$ emissions across 82 middle-income countries from 1980 to 2012, finding that trade openness leads to a reduction in $CO_2$ emissions in both high- and middle-income countries. Likewise, Al-Mulali et al. (2015) emphasized that trade openness results in a decrease in $CO_2$ emissions across 23 European countries from 1990 to 2013. Pham and Nguyen (2024) examined the relationship between trade openness and $CO_2$ emissions in 64 selected developing countries from 2003 to 2017, concluding that trade openness does not significantly impact environmental quality.

### 2.4. A Brief Overview of Gaps in the Literature

Despite the substantial contributions of prior studies, several critical knowledge gaps remain, which this study aims to address. Our review indicates that few studies have analyzed the effects of economic factors on $CO_2$ emissions within the context of the Middle East, particularly in Jordan. To date, no study has been conducted to explore the intricate relationship between environmental quality and economic growth dynamics in Jordan, leaving the specific mechanisms of this connection largely unexplored. Most existing studies tend to focus on individual factors, examining their relationships or impacts on environmental degradation without considering the broader context. In contrast, this study considers multiple economic factors, including financial development, FDI, trade openness, and economic growth. Additionally, the current literature presents conflicting results regarding the relationship between economic factors and environmental quality. These contradictions may arise from variations in the econometric models employed in data analysis. Thus, this study employs two techniques: the ARDL approach and the VECM model. This dual approach enables a comprehensive exploration of both long-run and short-run relationships among the dependent and independent variables, as well as the causal relationships that exist among all variables. The impacts of financial development, FDI, and trade openness on environmental quality have consistently been significant areas of research, and this study aims to contribute to that growing body of work. Utilizing time series data from 1990 to 2022, this study conducts an in-depth analysis of many economic dynamics affecting environmental quality in Jordan.

## 3. Materials and Methods

### 3.1. Data and Measurement

The primary objective of this research is to investigate the impact of financial development, FDI, and trade openness on $CO_2$ emissions in Jordan from 1990 to 2022. The study utilizes time series data sourced from the World Development Indicators (WDI), published by the World Bank in 2023. $CO_2$ emissions are measured in metric tons per capita, a method widely used by several researchers, including Shahbaz et al. (2019), Aldegheishem (2024), Wang et al. (2024), Thi et al. (2023), and Chhabra et al. (2022).

Financial development (FD) is measured as domestic credit to the private sector as a percentage of GDP, following the methodologies of Wang et al. (2023), Suhrab et al. (2023), and Al-Mulali et al. (2015). FDI is assessed through net inflows of FDI as a percentage of GDP, in line with the approaches of Wencong et al. (2023), Apergis et al. (2023), and Abdul-Mumuni et al. (2023). Trade openness (TRO) is measured as a percentage of GDP, consistent with the methods of Eweade et al. (2023) and Chhabra et al. (2022).

### 3.2. Empirical Model

This study examines the relationships between FD, FDI, TRO, and $CO_2$ emissions in Jordan. To strengthen the empirical model, we include three control variables: economic growth (EG), measured as a GDP per capita (constant 2015 USD); renewable energy consumption (REC), estimated as a percentage of total final energy consumption; and non-renewable energy consumption (NREC), expressed as a total energy consumption/quad Btu. The data for EG and REC were obtained from the World Bank (2023), while NREC was sourced from the Energy Information Administration (2023).

The study employs both the ARDL technique and the VECM Granger causality approach. These methods allow for a comprehensive examination of both long-run and short-run relationships among the variables, including the assessment of causality. Additionally, they enhance the robustness of the findings and provide a holistic view of the factors affecting $CO_2$ emissions.

The ARDL model is employed to explore the relationships among the study variables. Researchers such as Anwar et al. (2022), Abid et al. (2022), Usman et al. (2022), Essandoh et al. (2020), Abdul-Mumuni et al. (2023), and Zheng et al. (2024) have widely utilized the ARDL approach to investigate economic factors affecting environmental degradation. This model is particularly suitable for this study, especially when the variables are stationary at I(0) or integrated of order I(1) (Pesaran et al. 2001). The ARDL approach provides realistic and efficient estimates by capturing both short-term and long-term impacts of the research variables (Pesaran et al. 2001).

The VECM approach, developed by Engle and Granger (1987), is utilized to analyze both the long-run equilibrium relationships among the variables and the short-run dynamics associated with these relationships. This technique allows for the assessment of the effects of policy changes or external shocks on the variables, which is valuable for researchers and policymakers aiming to understand the impact of economic policies on environmental quality. Additionally, the VECM facilitates the execution of causality tests, as indicated by Engle and Granger (1987), which are essential for determining causal relationships among the variables. Establishing these relationships is crucial for understanding the direction of effects among the study variables and other factors in Jordan.

To define the relationship among FD, FDI, TRO, EG, NREC, REC, and $CO_2$ emissions, the first equation is formulated based on the work of Narayan and Narayan (2010) as follows:

$$CO_{2t} = f(FD_t, FDI_t, TRO_t, EG_t, NREC_t, REC_t) \quad (1)$$

The model can be defined as outlined in Equation (2)

$$CO_2 = \alpha_0 + \beta_1 \times FD_t + \beta_2 \times FDI_t + \beta_3 \times TRO_t + \beta_4 \times EG_t + \beta_5 \times NREC_t + \beta_6 \times REC_t + e_t \quad (2)$$

Natural logarithms provide a suitable linear specification for panel estimation and can be effectively used, as outlined in the third equation by Narayan and Narayan (2010).

$$LnCO_2 = \alpha_0 + \beta_1 \times LnFD_t + \beta_2 \times LnFDI_t + \beta_3 \times LnTRO_t + \beta_4 \times LnEG_t + \beta_5 \times LnNREC_t + \beta_6 \times LnREC_t + e_t \quad (3)$$

where Ln denotes the natural logarithm, $\alpha_0$ is a proxy for the constant, $\beta_1$ to $\beta_6$ are the coefficients of the model, and $e_t$ refers to the random error term. The expression of the ARDL model is formulated by Equation (4):

$$\begin{aligned} DLnCO_{2t} = \beta_0 & + \sum_{i=1}^{p} \gamma_i DLnCO_{t-1} + \beta_1 LnCO_{2t-1} + \sum_{i=1}^{q} \delta_i LnFD_{t-1} + \beta_2 FD_{t-1} + \sum_{i=1}^{q} \epsilon_i LnFDI_{t-1} + \beta_3 FDI_{t-1} \\ & + \sum_{i=1}^{q} \vartheta_i LnTRO_{t-1} + \beta_4 TRO_{t-1} + \sum_{i=1}^{q} \mu_i LnEG_{t-1} + \beta_5 EG_{t-1} + \sum_{i=1}^{q} \pi_i LnNREC_{t-1} + \beta_6 NREC_{t-1} \\ & + \sum_{i=1}^{q} \tau_i LnREC_{t-1} + \beta_7 REC_{t-1} + e_t \end{aligned} \quad (4)$$

The first-difference operator is denoted by D. The symbols $\gamma$, $\delta$, $\epsilon$, $\vartheta$, $\mu$, $\pi$, and $\tau$ represent the dynamics of error correction. The coefficients $\beta_1$ to $\beta_7$ indicate the long-term relationships among the variables of the ARDL model. The optimal lags are specified by the parameters p and q.

Based on the work of Pesaran et al. (2001), we employ the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests to assess the presence of unit roots in the time series data. The ADF and PP tests help determine the stationarity of the study variables. Cointegration between the variables is indicated when the estimated F value exceeds the upper critical bound, while the absence of cointegration is suggested when the F value falls below the lower critical bound (Pesaran et al. 2001). Therefore, the main hypothesis of this study can be formulated as follows:

**H0.** *$\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$ (there are no long-run relationships among the variables).*

**H1.** *$\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 = 0$ (there are long-run relationships among the variables).*

In this study, we utilize the unit root test developed by Zivot and Andrews (1992), which enables the identification of structural breaks within the data. This leads to the formulation of the following fifth equation:

$$y_t = \mu_1 + Y_{t-1} + dD(T_B)_t + (\mu_2 - \mu_1)DU_t + \varepsilon_t \quad (5)$$

where $D(T_B)_t = 1$ if $t = T_B + 1$, 0 otherwise; $DU_t = 1$ if $t > T_B$ (Zivot and Andrews 1992, p. 6). This approach allows for an exogenous change in both the level of the series and the rate of growth (Zivot and Andrews 1992, p. 6).

The Bounds test is used to identify long-term cointegration among the variables in the model. Subsequently, the VECM technique, a restricted form of the Vector Autoregression (VAR) model, is employed to determine the direction of short-run causal relationships between the variables (Engle and Granger 1987). The error correction term (ECT) signifies the degree to which the disequilibrium from the previous period affects the adjustments in the current period (Engle and Granger 1987). The coefficient of the ECT should be both significant and negative, reflecting the speed of short-term adjustments toward equilibrium (Engle and Granger 1987). Based on the work of Narayan and Smyth (2006), the VAR approach can be formulated as outlined in the sixth equation.

$$DLnCO_{2t} = Z_0 + \sum_{i=1}^{p} \gamma_i DLnCO_{t-1} + \sum_{i=1}^{q} \delta_i LnFD_{t-1} + \sum_{i=1}^{q} \epsilon_i LnFDI_{t-1} + \sum_{i=1}^{q} \vartheta_i LnTRO_{t-1} + \sum_{i=1}^{q} \mu_i LnEG_{t-1} + \sum_{i=1}^{q} \pi_i LnNREC_{t-1} + \sum_{i=1}^{q} \tau_i LnREC_{t-1} + e_t \quad (6)$$

The VECM identifies both the long-run relationships and the short-run dynamics between the study variables through the error correction term (ECT). The ECT measures the distance between the variables and their long-run equilibrium (Engle and Granger 1987). Furthermore, the VECM shows how the variables within the model converge toward their long-run equilibrium over time. Based on Engle and Granger (1987), the VECM can be formulated as follows:

$$DLnCO_{2t} = \Pi_0 + \sum_{i=1}^{p} \gamma_i DLnCO_{t-1} + \sum_{i=1}^{q} \delta_i LnFD_{t-1} + \sum_{i=1}^{q} \epsilon_i LnFDI_{t-1} + \sum_{i=1}^{q} \vartheta_i LnTRO_{t-1} + \sum_{i=1}^{q} \mu_i LnEG_{t-1} + \sum_{i=1}^{q} \pi_i LnNREC_{t-1} + \sum_{i=1}^{q} \tau_i LnREC_{t-1} + \varphi ECT_{t-1} + e_t \quad (7)$$

In effect, $\Pi$, $\gamma$, $\delta$, $\epsilon$, $\vartheta$, $\mu$, $\pi$, $\tau$, and $\mu$ denote the factors, while $e_t$ represents the white noise error term. Additionally, $\varphi$ECT serves as a proxy for the error correction term.

Finally, this research employs the Cumulative Sum (CUSUM) test and the Cumulative Sum of Squares (CUSUMSQ) test to verify the model's stability. Additionally, a series of diagnostic tests, including those for functional form, serial correlation, heteroscedasticity, and normality, are conducted to ensure the robustness of the model.

## 4. Empirical Results and Discussion

### *4.1. Descriptive Statistics*

Table 1 presents the descriptive statistics of the study variables and the primary characteristics of the data. All variables exhibit a positive average, suggesting an overall positive trend. The growth of $CO_2$ emissions is linked to an increase in FD, FDI, TRO, and GDP. FD has grown significantly over the years, influenced by various factors, including the banking sector growth, economic reforms, regulatory frameworks, and regional economic dynamics. The contribution of FDI to GDP is relatively satisfactory, which may be attributed to the global decline in FDI inflows. Over the last two decades, Jordan has utilized its strategic location as a gateway to markets in the Middle East to attract FDI through various incentives and reforms, focusing on sectors such as information technology, energy, tourism, and manufacturing. The continued improvement in TRO reflects Jordan's commitment to liberalizing its economy and integrating with global markets. The country has entered into several trade agreements, including the Association Agreement with the EU, Free Trade Agreements, and Qualifying Industrial Zones (QIZs). The descriptive statistics show that the GDP per capita is relatively low, suggesting that challenges to economic growth continue to exert pressure on the GDP. The results indicate that the use of renewable energy is limited, indicating that economic development primarily relies on non-renewable energy sources. Additionally, the standard deviation values are relatively low compared to the means, implying a lack of bias in the time series sample. Finally, the Jarque–Bera test is employed to verify the normal distribution. The *p*-value of the Jarque–Bera test is less than the significance level of 0.05. This result indicates that the distribution of variables is normal.

**Table 1.** Descriptive statistics.

| Variables | Obs | Mean | Min | Max | S.D | Jarque-Bera | *p*-Value |
|---|---|---|---|---|---|---|---|
| FD | 33 | 73.15099 | 55.89569 | 91.7686 | 7.718904 | 14.434 | 0.000 |
| FDI | 33 | 5.694465675 | −0.59839685 | 23.53729134 | 5.494643786 | 12.482 | 0.000 |
| TRO | 33 | 115.9452053 | 85.82107451 | 146.9088913 | 17.44379438 | 10.725 | 0.000 |
| EG | 33 | 3993.731 | 3454.806 | 4920.865 | 513.7347 | 8.943 | 0.013 |
| NREC | 33 | 0.273848 | 0.136 | 0.403 | 0.078689 | 15.682 | 0.000 |
| REC | 33 | 3.5 | 1.7 | 11.5 | 2.487128153 | 7.641 | 0.025 |
| $CO_2$ | 33 | 2.946458861 | 1.919172426 | 3.498966459 | 0.354087776 | 8.557 | 0.016 |

### 4.2. Results of Unit Root Tests

Table 2 presents the results of the unit root tests conducted for each time series. The findings indicate that the variables are stationary at their first difference but non-stationary at the level. These results meet the requirements for applying the ARDL model. Therefore, we reject the null hypothesis and accept the alternative hypothesis.

**Table 2.** Results of unit root tests.

| | ADF | PP | ADF | PP |
|---|---|---|---|---|
| | Level | | First Difference | |
| $LNCO_2$ | −2.870 | −3.741 | −7.618 ** | −7.213 ** |
| LNFD | −1.745 | −3.652 | −5.524 ** | −5.185 ** |
| LNFDI | −2.628 | −1.828 | −5.202 ** | −5.114 ** |
| LNTRO | −2.535 | −3.589 | −5.233 ** | −6.327 ** |
| LNEG | −2.318 | −1.723 | −5198 ** | −5.212 ** |
| LNNREC | −2.741 | −1.922 | −5.718 ** | −5.204 ** |
| LNREC | −1.698 | −3.512 | −5.497 ** | −5.177 ** |

** Significant at 0.05 level.

The results of Zivot and Andrews' structural break unit root tests, presented in Table 3, provide evidence that structural breaks are prevalent in the empirical studies, influencing both the independent variables and $CO_2$ emissions. Time series analyses may reveal structural changes caused by factors such as political or economic crises. It is important to note that the outcomes of unit root tests may be biased if structural changes exist within the time series data. Consequently, Zivot and Andrews' unit root tests are designed to identify structural breaks internally.

Table 3 illustrates that a structural break in $CO_2$ emissions occurred in 1992. This finding is significant, reflecting major transformations in both the population and economic structures of Jordan. During the early 1990s, many Jordanian workers returned from the Arab Gulf states, while financial aid was curtailed due to the country's official stance during the First Gulf War. Consequently, there was a notable increase in demand for energy and natural resources, leading to a rise in $CO_2$ emissions. The table also indicates a structural break date of 2005 for financial development, which reflects substantial economic changes in Jordan. This period (2003 to 2008) was marked by increased business and economic activities, primarily due to an influx of wealthy Iraqis following the American invasion of Iraq in 2003. In this context, a structural break for non-renewable energy was shown in 2004, while renewable energy experienced a break in 2019. Additionally, structural breaks for FDI were identified in 2015, while trade openness showed a break in 2006. Finally, a structural break for economic growth was noted in 2008, attributed to the global economic crisis.

**Table 3.** Zivot and Andrew's stationarity test for structural break estimations.

| Variables | First | | | First Difference | | |
|---|---|---|---|---|---|---|
| | T Statistic | Break Year | Outcome | T Statistic | Break Year | Outcome |
| $LNLCO_2$ | −3.658 | 1991 | Unit root | −6.708 ** | 1992 | Stationary |
| LNLFD | −5.674 ** | 2004 | Stationary | −8.431 ** | 2005 | Stationary |
| LNLFDI | −5.408 ** | 2012 | Stationary | −7.540 ** | 2015 | Stationary |
| LNLTRO | −4.395 | 2010 | Unit root | −6.005 ** | 2006 | Stationary |
| LNLEG | −4.761 | 2005 | Unit root | −9.763 ** | 2008 | Stationary |
| LNLNREC | −5.241 ** | 2003 | Stationary | −7.112 ** | 2004 | Stationary |
| LNLREC | −3.761 | 2018 | Unit root | −6.107 ** | 2019 | Stationary |

** Significant at 0.05 level.

According to Table 4, it should be noted that the maximum order of lag is fixed at 2. This determination is supported by Narayan and Smyth (2004), who established that the maximum number of lags in the ARDL model should be set to 2 when using annual data. Several criteria exist for determining the number of lags, with the Akaike Information Criteria (AIC) and the Schwarz Bayesian Criteria (SIC) being the most widely recognized (Anderson and Burnham 2002). For this study, we adopt the SIC, as it typically yields a more accurate model specification. The optimal lag was selected based on the AIC, with the optimal lag lengths reported in parentheses. By applying AIC to the variables, two lags were identified, as depicted in Table 4. The critical values for the unit root tests are −5.57 (1%), −5.08 (5%), and −4.82 (10%), as established by Zivot and Andrews (1992, p. 264), with AIC optimal lags of (0, 1, 0, 1, 1).

**Table 4.** Lagged selection Criteria.

| Lagged Selection Criteria | | |
|---|---|---|
| **Lag** | **Lag Log-Likelihood** | **AIC** |
| 0 | −568.2157 | 49.12179 |
| 1 | −483.3421 | 43.65378 |
| 2 | −476.4254 | 43.25443 |
| 4 | −479.4521 | 43.45252 |
| 5 | −488.1792 | 43.69146 |

## 4.3. Results of Cointegration Analysis

The application of the ARDL model assesses the long-run relationships between $CO_2$ emissions and the independent variables after confirming the order of integration. Table 5 presents the results of the F-test, revealing an estimated F value of 7.466. This value exceeds the critical threshold at the 1% level, indicating a significant long-term relationship between $CO_2$ emissions and the independent variables.

**Table 5.** ARDL-bound test.

| Critical Value Bounds | | F Value 7.466 |
|---|---|---|
| Sig | Lower bounds | Upper bounds |
| 1% | 2.571 | 4.06 |
| 5% | 3.723 | 5.682 |
| 10% | 4.912 | 7.224 |

### 4.3.1. Long Run ARDL Estimation

The long-run relationships among the variables are presented in Table 6. Specifically, FD, FDI, TRO, EG, and NREC have a positive impact on $CO_2$ emissions, which leads to an increase in environmental risks over extended periods. In contrast, REC does not have any significant effect on $CO_2$ emissions.

**Table 6.** Long-run ARDL elasticities.

| Variables | Coefficients | Std. Error | t Statistic | Prob. |
|---|---|---|---|---|
| FD | 0.388 | 0.111 | 3.595 | 0.002 |
| FDI | 0.347 | 0.109 | 3.183 | 0.006 |
| TRO | 0.426 | 0.116 | 3.672 | 0.003 |
| EG | 0.382 | 0.102 | 3.745 | 0.000 |
| NREC | 0.444 | 0.118 | 3.762 | 0.000 |
| REC | 0.198 | 0.107 | 1.850 | 0.118 |
| Constant | 6.454 | 2.024 | 3.188 | 0.009 |
| CUSUM | Stable | | | |
| CUSUMSQ | Stable | | | |
| Serial correlation | | 2.68 (0.03) | | |
| Heteroscedasticity | | 0.59 (0.51) | | |
| Functional Form | | 0.81 (0.42) | | |
| Normality | | 3.54 (0. 11) | | |

The findings reveal that a 1% increase in financial development leads to a 0.388% rise in $CO_2$ emissions in the long term, increasing environmental degradation. The expansion of the financial sector appears to hinder access to funding for environmentally friendly energy projects, instead promoting reliance on non-renewable energy sources. The results suggest that Jordan encounters a complex relationship between financial development and $CO_2$ emissions. Several factors have contributed to the increase in $CO_2$ emissions through financial development in Jordan. Firstly, financial development has improved access to credit and financial services, boosting consumer spending and leading to an increased demand for goods and services. This heightened consumption has resulted in higher emissions from both production and transportation. Secondly, financial development has accelerated urbanization, as individuals migrate to urban areas in search of better economic opportunities. Currently, the urbanization rate in Jordan stands at 92% (Arabeyyat et al. 2024). This urbanization has further contributed to increased energy consumption and emissions from transportation, heating, and electricity usage. Finally, financial development has facilitated various infrastructure projects, including roads, airports, and power plants, which often prioritize fossil fuel utilization and significantly contribute to rising emissions. Our empirical findings are consistent with the theoretical frameworks proposed by Usman and Hammar (2021) and Khezri et al. (2021), which argue that the expansion of financial development stimulates energy demand, thereby leading to an increase in $CO_2$ emissions. Thus, financial development directly contributes to environmental degradation by increasing energy consumption among both businesses and individuals. Although financial development achieves economic benefits across various sectors in Jordan, environmental policies are ineffective. Our results corroborate previous studies, including those by Shoaib et al. (2020), Wang et al. (2020), Ahmad et al. (2020), Qayyum et al. (2021), Ling et al. (2022), and Khezri et al. (2021), all of which support a positive correlation between financial development and $CO_2$ emissions. However, our findings contradict the conclusions of Rafique et al. (2020), Abid et al. (2022), and Usman et al. (2022), who reported that financial development leads to a reduction in $CO_2$ emissions.

Table 6 illustrates a significant positive impact of FDI on $CO_2$ emissions in Jordan over the long term. The results indicate that a 1% increase in FDI leads to a 0.347% rise in $CO_2$ emissions. This empirical evidence supports the PHH for Jordan, suggesting that environmental regulations are ineffective in protecting the environment. Many developing countries lack comprehensive environmental regulations (Aldegheishem 2024), leading multinational corporations—often adhering to stricter standards in their home countries—to relocate their operations to countries with more lenient regulations. These economic policies have mainly directed capital towards energy-intensive industries, such as mining and construction, which are heavily reliant on fossil fuels. Investment initiatives have largely focused on the phosphate, potassium, steel, and cement industries, all of which are essential to the Jordanian economy. These industries are generating employment opportunities and increasing export revenues. However, they also cause environmental risks that require the implementation of green practices to mitigate their adverse effects. Achieving a balance between economic growth and environmental sustainability continues to be a primary concern for these sectors. Overall, FDI inflows in Jordan remain limited. Our findings align with research by Javed et al. (2023), Pata et al. (2023), Raihan (2024), Wencong et al. (2023), Salahuddin et al. (2018), Lee (2013), Essandoh et al. (2020), Adjei-Mantey and Adams (2023), Abdul-Mumuni et al. (2023), and Zheng et al. (2024), all of which emphasize that FDI inflows stimulate $CO_2$ emissions.

The empirical findings reveal that trade openness has a positive impact on $CO_2$ emissions. Specifically, a 1% increase in trade openness leads to a 0.426% rise in $CO_2$ emissions in the long run, thus increasing environmental deterioration. According to the World Bank (2023), Jordan's GDP per capita is relatively low, averaging 3820 annually in 2022. It can be observed that a low GDP per capita may contribute to the importation of unsustainable goods, which are associated with high levels of pollution. This observation aligns with research by Shahbaz et al. (2017), which indicated that trade openness can lead to increased $CO_2$ emissions across various income levels. While trade openness may enhance environmental quality in high-income countries, it often results in environmental degradation in middle- and low-income countries. This trend reflects the transfer of carbon emissions during international trade (Essandoh et al. 2020). In Jordan, environmental standards are generally less stringent compared to those in developed countries, and the current environmental regulations are inadequate. As global supply chains expand, developed countries often transfer industries that generate carbon emissions to developing countries (Baumert et al. 2019). Consequently, as income levels rise, the influence of trade openness on environmental quality tends to shift from negative to positive. Our findings are consistent with research conducted by Chhabra et al. (2022), Ibrahim et al. (2024), Jiang and Liu (2023), Suhrab et al. (2023), Akhayere et al. (2023), Aldegheishem (2024), and Wang et al. (2024), all of which observed that trade openness results in higher $CO_2$ emissions. However, these results contrast with those of various other studies, including Thi et al. (2023), Hasanov et al. (2021), Sohag et al. (2017), Al-Mulali et al. (2015), and Pham and Nguyen (2024), which proposed that trade openness has a negative effect on $CO_2$ emissions.

Economic growth has a positive effect on $CO_2$ emissions. The findings indicate that a 1% increase in economic growth corresponds to a 0.542% increase in $CO_2$ emissions in the long term. This result suggests that economic growth does not improve environmental quality. These results align with previous research by Raihan (2023), Tsimisaraka et al. (2023), and Khan et al. (2019), which suggests that economic growth heightens energy demand and, consequently, contributes to rising $CO_2$ emissions. Furthermore, the economic challenges faced by Jordan—such as external debt, inflation, and unemployment—compel the government to prioritize economic growth over environmental considerations.

The results indicate that $CO_2$ emissions in Jordan are positively influenced by non-renewable energy consumption. The analysis reveals that a 1% increase in non-renewable energy consumption leads to a 0.444% increase in $CO_2$ emissions in the long term. Jordan's energy infrastructure is mainly reliant on imported fossil fuels, which are used to drive economic activities, thereby increasing environmental risks. Meanwhile, the results suggest that renewable energy does not contribute to reducing $CO_2$ emissions, primarily due to its limited use. This limitation is related to governmental practices regarding taxes and fees that discourage the transformation to renewable energy. The findings imply that the current energy policies are not effectively aligned with environmental goals. Our results are consistent with previous studies, such as (Musah et al. 2021; Wasti and Zaidi 2020; Khan et al. 2020; Alshehry and Belloumi 2015; Adedoyin et al. 2020; Kalmaz and Kirikkaleli 2019).

To assess the robustness of the model, the cumulative sum of residuals (CUSUM) and the cumulative sum of squares of residuals (CUSUMSQ) were used to evaluate structural stability. Appendix A, which includes Figures A1 and A2, provides a visual representation of CUSUM and CUSUMSQ. Both metrics fall within the established bounds at a significance level of 5%, indicating that the parameters of the model are stable. It is important to note that the scales for the CUSUM and CUSUMSQ axes are automatically determined by EViews 12 software, ensuring an accurate representation of model stability over the study period. Additionally, Table 6 shows that the functional form, serial correlation, heteroscedasticity, and normality specifications are all acceptable. When examining serial correlation, the null hypothesis of no serial correlation in the residuals cannot be rejected at the 1% significance level; however, it can be rejected at the 5% and 10% significance levels.

#### 4.3.2. Short Run Granger Causality and ECT Test

The outcomes of the ECT in Table 7 indicate a significant long-run relationship between the explanatory variables and $CO_2$ emissions. The negative and statistically significant coefficient associated with this relationship suggests that $CO_2$ emissions act as a critical adjustment mechanism when the econometric model deviates from its equilibrium state. This implies that any deviations from equilibrium will lead to corrections over time, highlighting the importance of $CO_2$ emissions in maintaining long-term balance within the model.

**Table 7.** Granger causality results and ECT test.

| Causality Method | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Short Run | | | | Long Run | | |
| | **DL$CO_2$** | **DLFD** | **DLFDI** | **DLTRO** | **DLEG** | **DNREC** | **DREC** | **ECT** |
| DL$CO_2$ | - | 0.328 ** 0.031 | 7.477 ** (0.018) | 0.651 ** (0.024) | 4.218 ** (0.032) | 4.433 ** (0.015) | −0.542 (0.838) | −2.088 ** (0.043) |
| DLFD | 2.844 ** (0.041) | - | 4.253 ** (0.028) | 3.762 ** (0.035) | 6.215 ** (0.017) | 6.519 ** (0.012) | 1.964 (0.782) | −0.118 ** (0.036) |
| DLFDI | 2.152 ** (0.036) | 4.029 ** (0.039) | - | 5.227 ** (0.039) | 5.88 ** (0.020) | 6.012 ** (0.018) | 1.842 0.122 | −1.742 ** (0.028) |
| DLTRO | 4.018 ** (0.025) | 2.240 ** (0.041) | 3.524 ** (0.036) | - | 3.892 ** (0.041) | 3.973 ** (0.038) | 0.068 (0.778) | −1.527 ** (0.019) |
| DLEG | 4.142 ** (0.018) | 2.983 ** (0.035) | 7.688 ** (0.011) | 4.758 ** (0.028) | - | 8.244 ** (0.013) | 0.974 (0.552) | −1.984 ** (0.012) |
| DNREC | 4.305 ** (0.022) | 3.088 ** (0.029) | 8.262 ** (0.012) | 5.128 ** (0.018) | 8.556 ** (0.022) | - | 1.652 (114) | −1.999 ** (0.010) |
| DREC | −0.016 (0.621) | −0.028 (0.638) | 0.038 (0.541) | −0.055 (0.122) | 0.043 (0.236) | 0.620 (0.824) | - | 0.764 (0.853) |

** significant at 5% level.

The Granger causality test reveals bidirectional causal relationships among the variables. In the short run, $CO_2$ emissions exhibit three bidirectional causal relationships with financial development, FDI, and trade openness. Specifically, the relationship between $CO_2$ emissions and financial development suggests that an increase in financial development significantly contributes to rising $CO_2$ emissions, thereby stimulating environmental degradation. This result underscores the role of financial development not only as a driver of economic growth, but also as a factor that may adversely affect environmental quality in Jordan.

The findings indicate that FDI contributes to an increase in $CO_2$ emissions. While FDI provides several benefits, including the introduction of new technologies and the enhancement of production capacities, it does not contribute to a reduction in $CO_2$ emissions in Jordan. This is because of the country's strategy of prioritizing FDI as a means to address economic challenges. As economic development expands, investments in both the service sector and infrastructure grow, resulting in heightened demand for energy and natural resources. Consequently, the expansion of FDI adversely affects environmental quality, highlighting the need for more effective environmental policies to be implemented in line with economic initiatives.

The short-run results indicate that trade openness positively impacts $CO_2$ emissions, suggesting that increased trade openness leads to higher emissions. This reflects a government focus on financial returns over environmental sustainability. For example, in September 2024, the Jordanian government increased the tax on electric vehicles to reach 55% in order to enhance its financial revenues. Such policies ultimately contribute to further environmental degradation, highlighting a mismatch between economic strategies and environmental sustainability efforts. This situation underscores the need for a more balanced approach that prioritizes both economic growth and environmental protection simultaneously.

The short-run results illustrate that financial development has bidirectional causal relationships with both FDI and trade openness, as well as with economic growth. These results indicate that fluctuations in financial development can influence and be influenced by FDI and trade dynamics. Furthermore, there is a bidirectional causal relationship among FDI, trade openness, and economic growth, highlighting the intricate interdependencies among these factors. These findings underscore the need for cohesive policy frameworks that consider these interactions to effectively tackle environmental challenges in Jordan.

The results show that several control variables have played an important role in affecting environmental quality. Economic growth has a positive effect on $CO_2$ emissions. Since the early 2000s, the Jordanian economy has been benefiting from economic openness. This in turn caused an increase in environmental risks as result of the expansion of economic activities, particularly in the manufacturing and mining sectors. Additionally, non-renewable energy consumption has a positive impact on $CO_2$ emissions in the short run, while renewable energy does not have an effect on $CO_2$ emissions. These results suggest that Jordan is heavily reliant on non-renewable energy, increasing environmental degradation. The investment in renewable energy requires high costs, which are ultimately borne by end users. Consequently, the contribution of renewable energy to improving environmental quality is limited at the initial phases of its use.

## 5. Conclusions and Policy Implications

This study investigates the impact of financial development, FDI, and trade openness on $CO_2$ emissions in Jordan from 1990 to 2022. Utilizing the ARDL approach and the VECM model, the present study examines both short- and long-term relationships, as well as the causal relations among these variables. In the long run, the results from the ARDL show that all explanatory variables positively influence $CO_2$ emissions. In the short run, the results of the VECM model indicate that all explanatory variables similarly have a positive effect on $CO_2$ emissions. The results from the two models illustrate that financial development, FDI, and trade openness contribute to environmental degradation in Jordan. These findings emphasize the need for more effective environmental policies that balance economic growth with environmental sustainability.

The empirical findings imply a considerable mismatch between economic policies and environmental objectives. A significant insight derived from this study is that the relationship between the economy and the environment does not contribute to improving environmental quality unless it is accompanied by effective economic–environmental policies. Currently, Jordan depends greatly on imported non-renewable energy to meet its economic and population needs. At the same time, current policies do not encourage the use of renewable energy. As economic development expands daily, the demand for energy will continue to increase, requiring a transformation from non-renewable energy to renewable energy. Therefore, the electrification of the economy can be seen as one of the best solutions in case of Jordan, as it improves environmental quality and maximizes economic benefits. Although the electrification of the economy may result in diminished taxes, it is expected that citizens' capacity to save will improve. This increase in savings is likely to stimulate consumer spending and raise purchasing power, thereby boosting economic growth cycle and contributing to further economic development. Furthermore, the transformation to an electrified economy is expected to lower costs across various economic sectors, such as industry, agriculture, and transportation. The electrification of the economy requires attracting investment in renewable energy and clean technologies by providing a series of incentives. These investments will not only contribute to the generation of additional employment opportunities in the manufacturing and construction sectors, but they will also facilitate the attainment of economies of scale in renewable energy technologies, thereby lowering the costs associated with these energy sources. Replacing non-renewable sources with clean, renewable sources such as wind and solar power, along with the provision of subsidies for environmentally sustainable technologies and the implementation of regulations aimed at decarbonization, can decrease carbon emissions.

The modification of current trade structure may help mitigate $CO_2$ emissions. The current trade structure is based highly on imports which do not provide real value to the national economy or environmental policies. Therefore, the focus on local exportable industries can enhance economic development and reduce $CO_2$ emissions. The increase in exports can raise returns on investment and improve both technical support and competitive advantage. Consequently, modifying the current trade structure necessitates a reevaluation of the industrial structure to lower reliance on secondary industries and the shift from energy-intensive production techniques towards green practices that leverage renewable energy sources and clean technologies. To facilitate this transformation, it is necessary to leverage trade openness as a means to encourage non-polluting industries. This can be achieved by imposing taxes on polluting industries and providing incentives for non-polluting industries, thereby encouraging investors to adopt green practices. The implementation of these policies can enhance overall energy efficiency, which, in turn, contributes to a reduction in $CO_2$ emissions associated with increased economic activity.

Financial development plays a significant role in contributing to environmental degradation. However, the financial sector possesses the capability to initiate projects aimed at reducing $CO_2$ emissions. Furthermore, this sector can support business activities by offering loans that depend on adherence to environmental preservation standards. Additionally, it is imperative for the government to prioritize financial development within its policy framework. Such advancements would not only enhance sustainable development but also strengthen the regulatory framework for financial firms.

The findings of this study significantly enhance our understanding of the interrelationships among financial development, FDI, trade openness, economic growth, and $CO_2$ emissions in Jordan. These insights support the theoretical relationships among these variables, environmental quality, and the implementation of sustainable policies within the Jordanian context. However, this study is not exempt from some limitations. It has assessed the impact of four economic factors on $CO_2$ emissions, therefore, future studies should consider other variables, such as technological innovation and transportation, as well as industrialization. These variables may provide a more comprehensive perspective on the relationship between economic development and environmental quality. Another limitation is the reliance on a single case study; as a result, future research should expand the sample to include other Middle Eastern countries, enabling comparative analyses that may yield broader conclusions. Such studies could provide a more thorough understanding, ultimately facilitating efforts to improve environmental conditions and promote sustainable development in the Middle East.

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## Appendix A

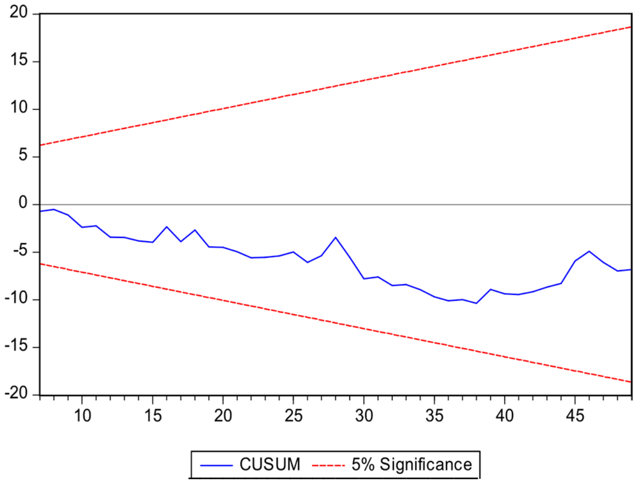


**Figure A1.** Plot of CUSUM.

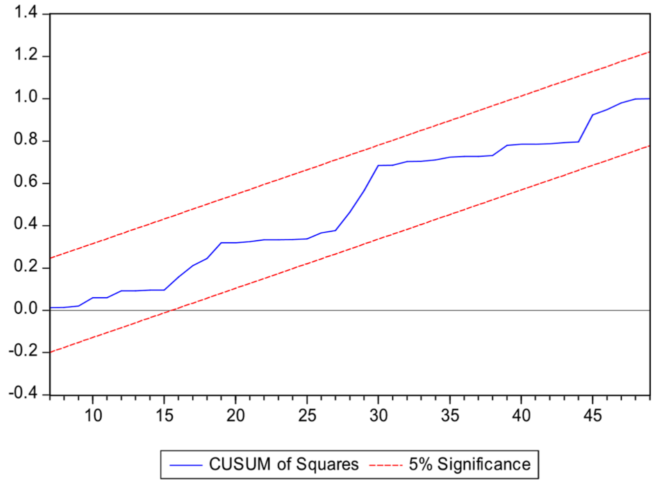


**Figure A2.** Plot of CUSUMsq.

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