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# Dynamic relationship among carbon dioxide emissions, energy consumption and economic growth

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**A B S T R A C T**

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The present research analyzes the short and long run relationship between Energy Consumption, Economic growth, and Carbon Dioxide emissions in Jordan. The study employs two (2) models: 1: Autoregressive Distributed Lag (ARDL) bound testing approach and 2: Vector Error Correction Model (VECM) Granger causality and impulse response function. The results reveal that energy consumption has a positive impact on carbon dioxide emissions and in turn carbon dioxide emissions have a positive link to economic growth. Further, the Environmental Kuznets Curve (EKC) hypothesis is tested, and it reveals that the EKC hypothesis is validated in the case of Jordan since the carbon dioxide emissions show a significant impact on economic growth in the short and long run. The study provides important results for future researchers and government policy makers.



## 1. Introduction

Environmental degradation is considered as one of the most complicated problems for industrialized and non-industrialized economies (Kollias et al., 2017; Say & Yücel, 2006). Different factors such as carbon dioxide (CO2) emissions contribute to greenhouse gas emission that causes environmental degradation (Owusu & Asumadu-Sarkodie, 2016; Sarkodie & Strezov, 2018). However, countries are utilizing energy to attain maximum economic growth that positively influences greenhouse gas emissions. In the recent two decades, the relationship between economic growth (GDP), energy consumption (EC) and CO2 has become an interesting topic in environmental science and energy economics. In economics, the environment is considered as the base that holds all economic activities and the base of the sustainability of life. Several studies have examined the relationship between economic growth, use of energy and CO2 in different regions and countries. For instance, Akinlo (2008) and Apergis and Payne (2009) in their studies confirmed the existence of a significant correlation between energy consumption and economic growth, and that energy consumption affects economic growth positively. Wang (2012) and Wang et al. (2013) reveal that economic growth is a crucial factor and has a significant positive impact on CO2 emissions in China. In fact, CO2 emissions have been recently considered an international problem due to the adverse effect of these emissions on climate changes (Boutabba, 2014). For Jordan, CO2 emissions and overall energy intensity of GDP is higher than most Middle East and North Africa (MENA) countries. For instance, CO2 emissions reached 3.65, 3.52 and 3.52 metric tons per capita in 2005, 2006 and 2007, respectively, which is a large amount compared to other countries such as Egypt that got 2.21, 2.32 and 2.41 in the same period. Further, the total greenhouse gas (GHG) emissions grew 59 percent from 1990-2011. In the same time period, gross domestic product (GDP) grew by 2.12 percent. Therefore, carbon dioxide is considered an important factor in economic growth, and therefore the study develops a model that analyses the impact of energy consumption, carbon dioxide emission on economic growth in Jordan. The present research contributes to energy economics in three ways: (i), it examines the relationship between energy consumption, carbon dioxide emissions and economic growth for an economic emerging

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country (Jordan). (ii), we test the environmental Kuznets curve (EKC) hypothesis for the period 1977-2014. (iii), VECM Granger causality is applied to detect the direction of causality relationship among variables.

## 2. Literature review

Although several studies examine the relationship between energy consumption (EC), carbon dioxide (CO2) and economic growth (GDP), the results show inconsistency. Some of these studies find a positive relationship while others show a negative link. For instance, Nain, Ahmad and Kamaiah (2017) evaluate the relationship between energy consumption (EC), economic growth (GDP) and carbon dioxide (CO2) in India. They employ the ARDL and granger causality test, and they find that there is a co-integration relationship among variables. Moreover, they conclude that there are unidirectional causality relationships running from EC to GDP as well as from CO2 to GDP, and a bidirectional causality relationship between CO2 and EC. Saboori and Sulaiman (2013) examine the relationship between EC, CO2 and GDP using the ARDL bound testing approach and VECM Granger causality for Southeast Asian Nation countries (Malaysia, Philippines, Thailand, Indonesia and Singapore). They find a significant positive relationship between EC and CO2 in all countries. On the other hand, a significant negative relationship between GDP and CO2 in Indonesia and the Philippines while positive link in Singapore and Thailand. Further, they found that there was a long run causality relationship running from EC and GDP to CO2 in all countries. Finally, they reveal that the Environmental Kuznets Curve (EKC) hypothesis is validated in the case of Thailand and Singapore.

In the US, Menyah and Wolde-Rufael (2010) study the causality relationship between CO2, renewable and nuclear energy consumption, and GDP. They applied for the Toda-Yamamoto of Granger non-causality test. They found a unidirectional causality relationship running from nuclear energy consumption to CO2 while a bidirectional causality relationship between GDP and CO2. Chang (2010) applies the vector error correction model (VECM) to detect the causality relationship between CO2, energy consumption (crude oil, coal, natural gas) and GDP in China. They reveal a unidirectional causality relationship running from GDP to CO2 and coal, they find a bidirectional causality relationship between CO2 and coal. Halicioglu (2009) studied the causal relationships between carbon emissions, energy consumption, income, and foreign trade in Turkey. He found a unidirectional causality relationship running from GDP to CO2, while a bidirectional causality relationship between EC and CO2. In another study, Ozturk and Acaravci (2010) employ the ARDL bound testing approach and Granger causality test and they found that there is a significant relationship among variables in the long run. Further, they reveal that there are unidirectional causality relationships running from EC to CO2 as well as from CO2 to GDP. They conclude that the Environmental Kuznets Curve (EKC) hypothesis was validated in the case of India and China.

Muhammad (2019) uses the generalized method of moments (GMM) and the system generalized method of moments (System GMM) to evaluate the effect of energy consumption, CO2 emissions and economic growth on each other in developed and emerging economies. The results concluded that EC negatively affects GDP in emerging economies. Further, GDP increases the CO2 in developed and emerging countries. Acheampong (2018) evaluated causality analysis to examine the causal relationship among GDP, CO2 emissions and EC in 116 countries, using panel vector autoregression (PVAR) and System-GMM model. The study finds that EC positively causes CO2 in MENA countries but negatively in sub-Saharan Africa and Caribbean-Latin America. Further, he reveals that EC positively causes GDP in sub-Saharan Africa while it shows a negative impact in MENA countries and Caribbean-Latin America. Indeed, the study finds evidence of the environmental Kuznets curve in sub-Saharan Africa.

## 3. Methodology

This study investigates the impact of energy consumption and CO2 emissions on economic growth in Jordan by utilizing annual time series data from 1977 to 2014. All data of this study were collected from the World Bank's World Development Index (WDI). In this research, energy consumption (EC) was measured as (kg of oil equivalent per capita), GDP per capita (US$) as a proxy of economic growth, and CO2 emissions as (metric tons per capita). Furthermore, to prevent diagnostics problems such as normality and heteroscedasticity, we transformed all variables into natural logarithm form (ln). The primary equation in the current research uses the following model:

$$lnCO2_t = \beta_0 + \omega_1 lnEC_t + \omega_2 lnGDP_t + \omega_2 lnGDP^2{}_t \varepsilon_t \quad (1)$$

where, $\beta_0$ is the intercept term, $\omega_1, \omega_2\ and\ \omega_3$ are the coefficients of variables, $lnCO2\ lnEC$, $lnGDP$, $lnGDP^2$ denote to the variables, carbon dioxide emissions, energy consumption, growth domestic product and square of growth domestic product, and $\varepsilon_t$ is the error term. This research applies the autoregressive distributed lag (ARDL) bound testing approach to examine the cointegration, short and long-run relationship among variables. Before applying the ARDL model, the unit root tests must be conducted to determine the stationary properties and the order of integration of the variables. If any variable in the study is non-stationary, the data analysis could lead to spurious regression results (Khan, Teng & Khan, 2019). This study employs the Augmented Dickey-Fuller (ADF) test, Phillips-Perron (PP) test and Kwiatkowski-Phillips- Schmidt-Shin (KPSS) test to determine the stationary properties. If the variables are stationary at their level or at their first difference, or in mixed integration i.e. some at I(0) and others at I(1), the ARDL bound testing approach produced by Pesaran, Shin and Smith (2001) can be used to detect the short and long-run relationship among variables (Abuoliem et al., 2019a; Ahmed, Zhang & Cary, 2021). The ARDL bound testing approach has additional advantages in comparison to other multivariate cointegration methodologies, which are as follows (Abuoliem et al., 2019b; Malik et al., 2020):

- The ARDL considers the serial correlation adequately and indigeneity among the variables and finally provides robust estimates if the appropriate lag-length is selected.
- The ARDL can be applied with a small sample size.
- The ARDL can be applied with the variable's stationary at their level or at their first difference or combination of both and does not require all variables to be stationary and integrated at the same order.
- The ARDL simultaneously evaluates the long and short-run dynamics of the models.

However, the ARDL bound testing approach is inapplicable if any variable of the study was stationary at the second difference I(2) or was non-stationary. In the current study, the equations of ARDL bound testing approach to examine the short and long-run relationship among the energy consumption, economic growth and Carbon dioxide emissions are as the following:

$$\Delta lnCO2 = \alpha_{11} + \theta_{11}\,\Delta lnCO2_{t-1} + \theta_{12}\,\Delta lnEC_{t-1} + \theta_{13}\,\Delta lnGDP_{t-1} + \theta_{14}\,\Delta lnGDP^2{}_{t-1} + \sum_{i=1}^{p}\beta_{11}\Delta lnCO2_{t-i} + \sum_{i=1}^{p}\beta_{12}\Delta lnEC_{t-i} + \sum_{i=1}^{p}\beta_{13}\Delta lnGDP_{t-i} + \sum_{i=1}^{p}\beta_{14}\Delta lnGDP^2{}_{t-i} + \varepsilon_{t1} \quad (2)$$

$$\Delta lnEC = \alpha_{21} + \theta_{21}\,\Delta lnCO2_{t-1} + \theta_{22}\,\Delta lnEC_{t-1} + \theta_{23}\,\Delta lnGDP_{t-1} + \theta_{24}\,\Delta lnGDP^2{}_{t-1} + \sum_{i=1}^{p}\beta_{21}\Delta lnCO2_{t-i} + \sum_{i=1}^{p}\beta_{22}\Delta lnEC_{t-i} + \sum_{i=1}^{p}\beta_{23}\Delta lnGDP_{t-i} + \sum_{i=1}^{p}\beta_{24}\Delta lnGDP^2{}_{t-i} + \varepsilon_{t2} \quad (3)$$

$$\Delta lnGDP = \alpha_{31} + \theta_{31}\,\Delta lnCO2_{t-1} + \theta_{32}\,\Delta lnEC_{t-1} + \theta_{33}\,\Delta lnGDP_{t-1} + \theta_{34}\,\Delta lnGDP^2{}_{t-1} + \sum_{i=1}^{p}\beta_{31}\Delta lnCO2_{t-i} + \sum_{i=1}^{p}\beta_{32}\Delta lnEC_{t-i} + \sum_{i=1}^{p}\beta_{33}\Delta lnGDP_{t-i} + \sum_{i=1}^{p}\beta_{34}\Delta lnGDP^2{}_{t-i} + \varepsilon_{t3} \quad (4)$$

$$\Delta lnGDP^2 = \alpha_{41} + \theta_{41}\,\Delta lnCO2_{t-1} + \theta_{42}\,\Delta lnEC_{t-1} + \theta_{43}\,\Delta lnGDP_{t-1} + \theta_{44}\,\Delta lnGDP^2{}_{t-1} + \sum_{i=1}^{p}\beta_{41}\Delta lnCO2_{t-i} + \sum_{i=1}^{p}\beta_{42}\Delta lnEC_{t-i} + \sum_{i=1}^{p}\beta_{43}\Delta lnGDP_{t-i} + \sum_{i=1}^{p}\beta_{44}\Delta lnGDP^2{}_{t-i} + \varepsilon_{t4} \quad (5)$$

where $\alpha_{11}$ ... $\alpha_{41}$ are the constant terms, Δ relates to the first difference, $\beta_{11}..\beta_{44}$ denote the short-run coefficients, $\theta_{11}..\theta_{44}$ are the long-run coefficients, while $\varepsilon_{t1}$ ... $\varepsilon_{t4}$ are the error terms. In the ARDL bound testing approach, the null hypothesis (H0: No co-integration relationship) could be tested against the alternative hypothesis (H1: co-integration relationship). In Eq. 1, the null and alternative hypotheses are accepted or rejected based on the following:

- Null hypothesis (H0) is not rejected and there is no co-integration relationship running from the energy consumption and economic growth to Carbon dioxide emissions if $\theta_1 = \theta_2 = \theta_3 = 0$.
- Null hypothesis (H0) is rejected, indicating that there is a co-integration running from the energy consumption and economic growth to Carbon dioxide emissions if $\theta_1 \neq \theta_2 \neq \theta_3 \neq 0$.

After the results of the short and long-run relationships, this study examines the direction of causality between the variables. Rahman and Kashem (2017) argue that if there are two or more variables that are co-integrated, then there is at least a one-way causality relationship between them. Further, the correlation among variables is not enough to understand the interaction between two or more time series, because some correlations maybe spurious and not useful, as there may be a third variable that is not accounted for, and therefore if the series are co-integrated, the causality test will be useful to determine the direction of causality relationship (Granger, 1969). Therefore, if the results of the co-integration test are confirmed among the variables, the vector error correction model (VECM) is applied to detect the causality relationship between the variables. If the results reveal no co-integration relationship, the vector autoregressive (VAR) model is applied to detect the causality relationship. In other words, in the presence of co-integration, the VECM model is confirmed to be appropriate to detect the causality relationship, because the vector autoregressive (VAR) model may produce misleading results (Saboori & Sulaiman, 2013; Ahmad, Du, Lu, Wang, Li & Hashmi, 2017). Indeed, the VECM model may have more advantages than the VAR model. For instance, the VECM model may detect the short-run causality using Wald test and F-statistic and the long-run causality using t-test, while the VAR model may detect the short-run causality relationship. Further, the VECM model allows the dependent variable to explain itself by its own lags and lags of explanatory variables as well as the error correction term (Shahbaz, Hye, Tiwari & Leitão, 2013). However, the causality relationship between lnEC, lnGDP and lnCO2 using the VECM granger causality model may be represented as the follows (Ahmad et al., 2017):

$$(1-L)\begin{bmatrix}\Delta lnCO2\\ \Delta lnEC\\ \Delta lnGDP\\ \Delta lnGDP^2\end{bmatrix} = \begin{bmatrix}\emptyset_1\\ \emptyset_2\\ \emptyset_3\\ \emptyset_4\end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix}\partial_{11} & \partial_{11} & \partial_{11}\\ \partial_{21} & \partial_{22} & \partial_{23}\\ \partial_{31} & \partial_{32} & \partial_{33}\\ \partial_{41} & \partial_{42} & \partial_{43}\end{bmatrix} \text{x} \begin{bmatrix}\Delta lnCO2\\ \Delta lnEC\\ \Delta lnGDP\\ \Delta lnGDP^2\end{bmatrix} + \begin{bmatrix}\delta_1\\ \delta_2\\ \delta_3\\ \delta_4\end{bmatrix}\text{ECT}_{t-1} + \begin{bmatrix}\varepsilon_{1t}\\ \varepsilon_{2t}\\ \varepsilon_{3t}\\ \varepsilon_{4t}\end{bmatrix} \quad (10)$$

where $(1-L)$ denotes to lag operator, $\partial_{11}\ldots\partial_{43}$ are parameters to be estimated, ECT is the error correction term. Further, the study employs the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests Brown, Durbin, and Evans (1975) produce to identify the stability of the results. The tests are important to identify if the model of the study is stable in the short and long-run or not, as well as to identify if there are any structural breaks in the model. Finally, this study employs diagnostic tests such Breusch-Godfrey Serial Correlation LM test, Jarque-Bera test and the heteroscedasticity (Breusch-Pagan-Godfrey) test to confirm the validity of the model under study.

## 4. Empirical results and discussion

### *4.1 Descriptive Statistics*

In Table 1, the descriptive statistics show that lnCO2 and lnEC with negative Skewness values while lnGDP and lnGDP2 show a positive Skewness value. Further, the results of the Jarque-Bera normality test indicate that the null hypothesis of a normal distribution is rejected for lnCO2 and lnEC, while accepted for lnGDP and lnGDP2. On the other hand, the multi-collinearity results show that the correlation value between the LEC and GDP is (-0.495). Rowntree (1981) suggests that when the correlation coefficient is from 0.41 to 0.69 it is categorized as a moderate correlation. Therefore, the results of this study indicate that there is no multi-collinearity problem among explanatory variables.

**Table 1**
Descriptive Statistics and Multicollinearity

| Descriptive Statistics | | | | |
|---|---|---|---|---|
| | lnCO2 | lnEC | lnGDP | $lnGDP^2$ |
| Mean | 1.036 | 6.797 | 7.556 | 57.251 |
| Median | 1.090 | 6.829 | 7.485 | 56.026 |
| Maximum | 1.295 | 7.054 | 8.326 | 69.326 |
| Minimum | 0.373 | 6.119 | 6.869 | 47.183 |
| Std. Dev. | 0.204 | 0.198 | 0.395 | 6.071 |
| Skewness | -1.921 | -1.854 | 0.622 | 0.704 |
| Kurtosis | 6.265 | 6.560 | 2.470 | 2.517 |
| Jarque-Bera | 40.267 | 41.864 | 6.899 | 3.507 |
| Probability | 0.000 | 0.000 | 0.234 | 0.173 |

| Multicollinearity | | |
|---|---|---|
| Variable | lnEC | lnGDP |
| lnEC | 1.000 | -0.495 |
| lnGDP | -0.495 | 1.000 |

*Source: Analyzed by the authors based on data from World Bank's World Development Index (WDI).*

### *4.2 Unit Root Tests*

Before applying the ARDL bound testing approach, the study must detect the stationary properties of the variables and that there are no variables that are stationary at their second difference I(2). The study adopts three-unit root tests in the current research namely the Augmented Dickey-Fuller test, Phillips-Perron test, and Kwiatkowski-Phillips-Schmidt-Shin test. The estimated results in Table 2 indicate that there are no variables that are stationary at I(2) while all variables are stationary at their level I(0) and their first difference I(1). Therefore, the ARDL approach is used in this study with the included data.

**Table 2**
Unit Root Results

| | lnCO2 | LnEC | lnGDP | $lnGDP^2$ |
|---|---|---|---|---|
| **Augmented Dickey-Fuller ADF** | | | | |
| Level | -4.83*** | -5.04*** | -0.18 | -0.133 |
| First-Difference | -3.21** | -5.19*** | -4.14*** | -4.05*** |
| **Phillips-Perron (PP)** | | | | |
| Level | -4.53*** | -4.93*** | -0.82 | -0.664 |
| First-Difference | -6.05*** | -5.19*** | -3.75*** | -3.76*** |
| **Kwiatkowski-Phillips-Schmidt-Shin (KPSS)** | | | | |
| Level | 0.527** | 0.559** | 0.519*** | 0.519*** |
| First-Difference | 0.322 | 0.336 | 0.203 | 0.219 |

**Notes: ***, **, * denote that the null of the unit root test is rejected at 1%, 5%, 10%, respectively. Used with an intercept and no trend.*
**Except for the KPSS, all unit-root tests have a null hypothesis that suggests (series has a unit root) against the alternative of being stationary. The null hypothesis of KPSS suggests that the variable is stationary.*

### *4.3 ARDL model selection*

The first step in the ARDL process is determining the optimal model. Pesaran and Shin (1998) argue that the AIC criterion and BIC criterion are the most famous criteria and appropriate for annual time series, especially with small sample sizes.

Therefore, the present research is based on AIC criterion to determine the optimal lag length for the model, and therefore, the results reveal that model ARDL (1, 2, 2, 2) is the optimal model in the current study.

**Table 3**
ARDL Model Selection

| Model | LogL | AIC* | BIC | HQ | Adj. R-sq | Specification |
|---|---|---|---|---|---|---|
| 28 | 81.786 | -3.932 | -3.448 | -3.763 | 0.959 | ARDL (1, 2, 2, 2) |
| 31 | 80.685 | -3.926 | -3.487 | -3.773 | 0.958 | ARDL (1, 2, 1, 2) |
| 29 | 80.547 | -3.919 | -3.479 | -3.765 | 0.957 | ARDL (1, 2, 2, 1) |
| 13 | 80.233 | -3.901 | -3.461 | -3.748 | 0.957 | ARDL (2, 1, 1, 2) |
| 10 | 81.131 | -3.896 | -3.412 | -3.727 | 0.957 | ARDL (2, 1, 2, 2) |

*Source: Analyzed by the authors.*

### *4.4 Bound Testing*

In order to estimate the co-integration association among the study variables, the ARDL bound test is used. In Table 4, for all models, the calculated F-statistic is greater than critical bounds at 10%, 5% and 1% indicating that there is a co-integration relationship and significant at 1% among variables. These results are similar to the results of Khan, Teng & Khan (2019) which reveal a co-integration relationship between energy consumption, economic growth and Carbon dioxide in Pakistan.

**Table 4**
Bound testing Results

| Model | F-statistic | Decision | Critical bounds | | |
|---|---|---|---|---|---|
| (lnCO2, lnEC, lnGDP, $lnGDP^2$) (1, 2, 2, 2) | 5.14*** | Co-integration | Sig | I(0) | I(1) |
| (lnEC, lnCO2, lnGDP, $lnGDP^2$) (2, 0, 2, 2) | 28.19*** | Co-integration | 10% | 2.63 | 3.35 |
| (lnGDP, lnCO2, lnEC, $lnGDP^2$) (1, 1, 0, 2) | 8.25*** | Co-integration | 5% | 3.1 | 3.87 |
| ($lnGDP^2$, lnCO2, lnEC, lnGDP) (2, 0, 1, 1) | 8.77*** | Co-integration | 1% | 4.13 | 5 |

*Notes: ***, **, * denote the significance level of 1%, 5%, 10%, respectively. Used with an intercept and no trend*

### *4.5 ARDL long and short run relationship*

Table 5 shows the results of the long and short-run relationship for the primary model in the study i.e. (lnCO2, lnEC, lnGDP, lnGDP2) (1, 2, 2, 2). First, the examined results below show that the error correction term ECT (-1) of the model is significant, negative and less than one in magnitude, which shows that the tendency of convergence to long-run equilibrium exists. The value of ECT (-1) below implies that any change in carbon dioxide emissions from short run towards long run of time is corrected by 27.54% every year.

**Table 5**
Long and Short Run Relationship

| Variable | Coefficient | Std. Error | t-Statistic | P-value |
|---|---|---|---|---|
| **Long-Run Relationship** | | | | |
| lnEC | 1.0151 | 0.0910 | 11.1483 | 0.0000*** |
| lnGDP | 2.2055 | 1.2401 | 1.7784 | 0.0875* |
| $lnGDP^2$ | -0.1416 | 0.0800 | -1.7697 | 0.0890* |
| C | -14.3986 | 4.4481 | -3.2081 | 0.0036*** |
| **Short-Run Relationship** | | | | |
| D(lnEC) | 0.9215 | 0.0802 | 11.4894 | 0.0000*** |
| D(lnEC (-1)) | -0.2067 | 0.0818 | -2.5260 | 0.0182** |
| D(lnGDP) | 4.6083 | 1.4204 | 3.2442 | 0.0033*** |
| D(lnGDP(-1)) | 2.3616 | 1.2905 | 1.8298 | 0.0792* |
| D($lnGDP^2$) | -0.3021 | 0.0948 | -3.1865 | 0.0038*** |
| D($lnGDP^2$(-1)) | -0.1684 | 0.0866 | -1.9449 | 0.0631* |
| ECT(-1) | -0.6970 | 0.1275 | -5.4632 | 0.0000*** |
| **Analysis Details and Diagnostic Statistics** | | | | |
| R-squared | 0.970 | | F-stat | 83.335 |
| Adjusted R-squared | 0.959 | | Prob. | 0.000 |
| Jarque-Bera Prob. | 0.332 | | Durbin-Watson | 2.315 |
| B-G LM Test Prob. | 0.163 | | ARCH | 0.247 |
| Heteroskedasticity test | 0.344 | | | |

*Notes: ***, **, * denote the significance level of 1%, 5%, 10%, respectively. Used with an intercept and no trend.*

Further, the results indicate that energy consumption has a significant positive influence on carbon dioxide in the long-run. These results indicate that a 1% increase in lnEC is linked with 1.01% increase in lnCO2 emissions. These results are similar to the results of Mahmud and Shahab (2014), Shahbaz et al. (2016) and Rahman and Kashem (2017). In addition, the results reveal that the linear term of growth of domestic product has a significant positive impact on CO2 emissions and whereas a negative impact of the square of growth domestic product on CO2 emissions is reported which is statistically significant at 10% level of significance. This implies that an inverted U-shaped relationship exists between real GDP per capita (square of real GDP per capita) and $CO_2$ emissions. The values of linear and nonlinear terms are 2.2055 and -0.1416. These findings support the environmental Kuznets curve (EKC) which suggests that economic growth increases $CO_2$ emissions initially and improves the environmental quality once the economy achieves threshold level of income per capita. These results provide evidence that the environmental Kuznets curve (EKC) is valid for the Jordan case. The results of the study are similar to results of Shahbaz, Ozturk, Afza and Ali (2013) and Bella (2018) who conclude that the environmental Kuznets curve (EKC) is valid for Turkey and France, respectively.

In the short-run relationship, the results show that current energy consumption D(LEC) has a significant positive relationship with carbon dioxide, while a one year lag of energy consumption D(LEC(-1)), has a significant negative relationship with carbon dioxide in Jordan. The coefficient of the current energy consumption (0.9215) indicates that an increase of one unit in lnEC would increase 0.9215 in lnCO2. Further, the results indicate that lnGDP and lnGDP2 have positive and negative signs p (inverted-U shaped relationship with $CO_2$ emissions) and are statistically significant. Specifically, the results show that lnGDP and one year lagged of lnGDP(-1) has a significant positive influence on lnCO2, while lnGDP2 and one year lagged of lnGDP2(-1) has a significant negative influence on lnCO2.

In contrast, determining the validity of the model, diagnostic statistics such as the Heteroscedasticity, ARCH, B-G autocorrelation LM Test and Jarque-Bera normality test are applied. The results below indicate that there are no diagnostic problems in the model. Further, the Durbin-Watson value (2.315) is close to two, which provides evidence that there is no autocorrelation problem in the residual (Aragón, Cerda, Delgado, Aguilar, & Navarro, 2019).

### *4.6 Stability Test*

In order to determine the robustness and the stability of the parameters of the long-run the study applied the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests. In the CUSUM and CUSUMSQ tests, the parameter and the model should exhibit stability if the plots remain within the 5 percent critical bound. In Fig. 1. The plots of both the CUSUM and CUSUMSQ are within the boundaries, and therefore the results indicate that the model is stable in the long run.

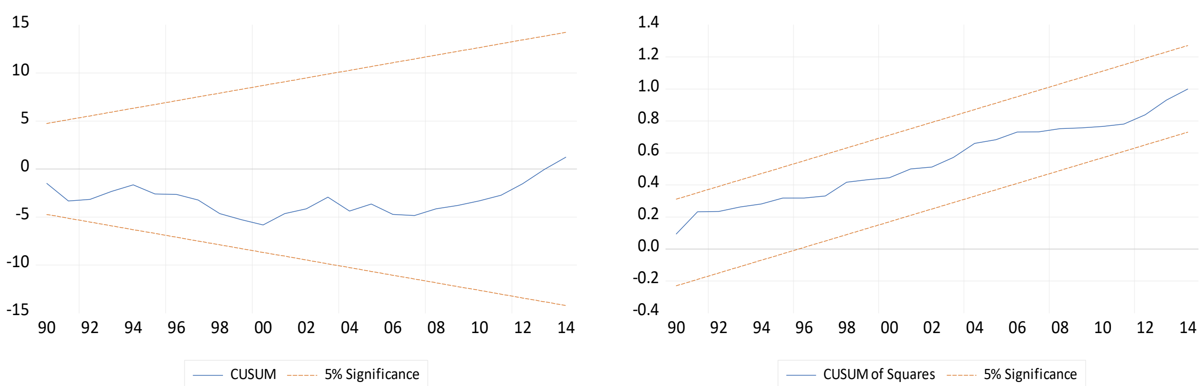


**Fig. 1.** Stability Results
Source: Analyzed by the authors

### *4.7 VECM granger causality*

In determining the direction of causality among variables we employed the VECM Granger causality test. In Table 6, the results show that there is a long run causality relationship running from the variables jointly to $CO_2$ emissions since the t-statistic is negative (-3.473) and significant at 5% significance level. Further, a long run causality relationship running from the variables jointly to energy consumption with a negative t-statistic (-5.200) and significant at 1%. On the short run causality, the examined results reveal that there are significant unidirectional causality relationships running from lnGDP to lnCO2 as well as from lnGDP2 to lnCO2. The results provide evidence that the Kuznets effect is valid for Jordan, as depicted in the environmental Kuznets Curve (EKC). Further, the study concludes that significant unidirectional causality relationships running from lnGDP to lnEC as well as from lnGDP2 to lnEC exist. These results support the results of Shahbaz et al. (2013a). Further, these results are similar to the results of Chen et al. (2016) that reveal a unidirectional causality relationship running from the gross domestic product to carbon dioxide in developed and developing countries.

**Table 6**
VECM Granger Causality Results

| | Direction of Causality | | | | |
|---|---|---|---|---|---|
| | Short-run | | | | Long-run |
| | $\Delta lnCO2_{t-1}$ | $\Delta lnEC_{t-1}$ | $\Delta lnGDP_{t-1}$ | $\Delta lnGDP^2_{t-1}$ | $ECT_{t-1}$ |
| $lnCO2_t$ | - | 0.332 | 5.146** | 5.001** | -3.473** |
| $lnEC_t$ | 0.316 | - | 3.733** | 3.683** | -5.200*** |
| $lnGDP_t$ | 0.049 | 0.006 | - | 0.158 | -0.116 |
| $lnGDP^2_t$ | 0.035 | 0.004 | 0.136 | - | -0.205 |

*Notes: ***, **, * denote the significance level of 1%, 5%, 10%, respectively. Used with an intercept and no trend.*

### *4.8 Impulse Response Function (IRF)*

The granger causality test examines the results for the causality relationship or the behavior of variables within the sample size and period, the test does not detect the behavior of variables not included in the sample (Payne, 2002). Therefore, this study employs the Impulse Response Function (IRF) to examine the behavior of the variables for 10 years out of the entire sample period. Figure 1 below shows the results of IRF which indicate that response of CO2 emissions to shocks in energy consumption is negative in the long run. In addition, the CO2 emissions are inverted U-shaped responses with economic growth. The results indicate that CO2 emissions rise and once the economy achieves the threshold level, then the CO2 emissions start falling with continued economic growth. These results are in line with the results of Shahbaz et al. (2013a) and Bella (2018).

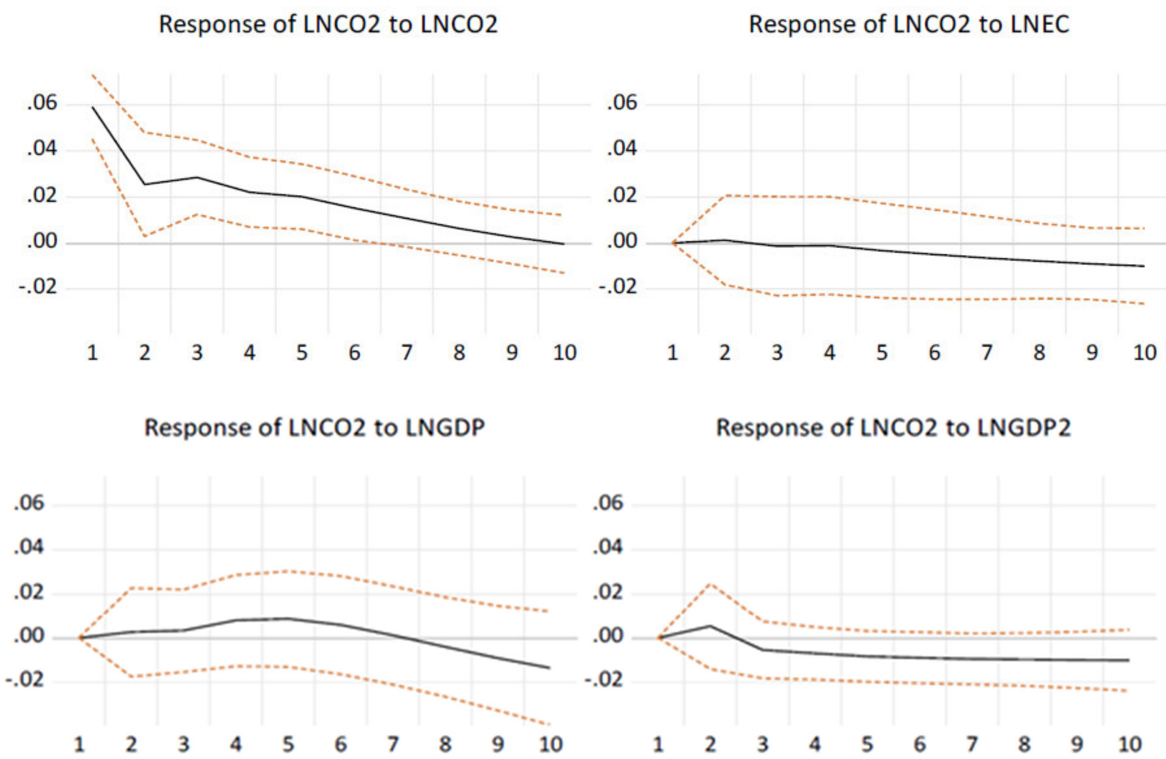


**Fig. 2.** Response of Carbon Dioxide emissions to Energy Consumption and Economic Growth.
Source: Analyzed by the authors

## 5. Conclusion

In the recent two decades, the relationship between economic growth, energy consumption and CO2 emission has become an interesting topic in environmental science and energy economics. In economics, the environment is considered as the base that holds all economic activities and the impetus of the sustainability of life. This study examines the relationship between energy consumption, economic growth and carbon dioxide emission in Jordan as well as tests the validity of EKC in Jordan. The study employs the autoregressive distributed lag (ARDL), the VECM Granger causality and impulse response function to detect the short and long-run link as well as the causality relationship among the variables. The results of the study reveal that energy consumption has a significant positive relationship with CO2 emission in the long run. Further, the results show that the linear term of growth domestic product has a significant positive impact on CO2 emission. Also, there is a negative impact of the square of real GDP per capita on CO2 emission that is reported and is statistically significant at 10% level of significance. This implies that an inverted U-shaped relationship exists between real GDP per capita and CO2 emission. On the other hand, the study finds unidirectional causality relationships running from lnGDP to lnCO2 as well as from lnGDP2 to lnCO2. The significant causality relationship between economic growth and CO2 emission indicates that the Kuznets effect is validated in the case of Jordan. The results of this study will be useful for future studies that focus on carbon dioxide. The government may use the results of the study to develop policies that aim at reducing CO2 emission. Further, future research can extend the results of this study by focusing on other variables, such as renewable energy, which is also considered an important variable in economic development.

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