INVESTIGATING THE DYNAMIC RELATIONSHIP BETWEEN ECONOMIC GROWTH, ENERGY CONSUMPTION, AND CO_2 EMISSIONS IN LEBANON

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1. Introduction

Climate change stands as a highly contested environmental concern on a global scale. The progression of economic development and globalization has played a significant role in elevating the concentrations of carbon dioxide (CO_2) emissions and various other greenhouse gases in our atmosphere. Over the past few

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decades, climate change has emerged as a crucial topic of conversation among political figures and knowledgeable individuals (Ozturk et al., 2010).[1]

Following the influential research conducted by Kraft et al. (1978), which was likely prompted by the oil price shock of 1973, the correlation between energy consumption and economic growth, commonly known as the energy-GDP nexus, has been extensively explored.[2] Numerous studies have delved into this subject, recognizing its significance.

In their pursuit of sustainable economic development and improved living standards, developing countries are consuming substantial amounts of energy. However, this increased energy consumption comes hand in hand with the emission of pollutants that significantly contribute to climate change (Alkhathlan et al., 2013).[3]

The rise in energy consumption and CO_2 emissions is an ongoing trend observed across various countries, with particular emphasis on developing nations like Lebanon. According to the Norwegian Refugee Council (2022), Lebanon hosts the largest proportion of refugees globally, which present 19.8 percent of the country's population.[4] Even more concerning is the impact of the aforementioned scenario on environmental quality. In Lebanon, the environment has consistently taken a backseat, primarily due to the presence of an inadequate institutional and legislative framework. The country also faces challenges in implementing effective policies to address environmental issues, alongside political obstacles that hinder the implementation of sustainable reforms (World Bank, 2022).[5] For example, Lebanon is currently grappling with an energy deficit, and certain regions, particularly rural areas, continue to lack access to electricity. The demand for energy in the country surpasses the available supply. Compounded by a struggling economy, Lebanon faces challenges in importing fossil fuels on a significant scale. The combination of energy deficiencies, limited electrification, and economic constraints presents complex obstacles for meeting the energy needs of the country. In addition, Lebanon is suffering from CO_2 emissions and experiencing a rise in pollution-related incidents. The severity of these incidents is more pronounced in urban neighbourhoods, primarily due to the escalating emissions in these densely populated areas, including Beirut city (Mokalled et al., 2018; Saliba et al., 2010; and Massoud et al., 2011).[6]

The aim of this research paper is to investigate the correlation between GDP growth, energy consumption, and CO_2 emissions in Lebanon from 1970 to 2021.

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The choice to focus on Lebanon as a case study is driven by several reasons. Firstly, despite the abundance of studies exploring the energy-GDP relationship, there is a scarcity of research that specifically examines Lebanon. Secondly, Lebanon presents a unique situation as both an energy-consuming country and one grappling with CO_2 related challenges. Thirdly, Lebanon faces economic, social, and geographical threats, which adds an additional layer of significance to the study. Lastly, previous studies in Lebanon have not adequately addressed the role of CO_2 emissions.

2. *Brief Literature Review*

Extensive scientific inquiry has been dedicated to investigating the intricate interplay among energy consumption, carbon dioxide emissions, and economic growth across diverse contexts. Numerous studies have diligently examined these relationships within distinct countries and regions, imparting significant understanding of the underlying dynamics at play in this domain.

Abbasi et al. (2021) observed the negative impact of CO_2 emissions while energy consumption, industrial growth, and urbanization had positive impacts on Pakistan's economic growth.[7] Acaravci et al. (2010) found a two-way causal relationship between energy consumption and economic growth in Europe, with increased CO_2 emissions adversely affecting economic growth.[8] Acheampong (2018) demonstrated that there is a bidirectional causal relationship between CO_2 emissions and energy consumption, and that economic growth has a unidirectional impact on CO_2 emissions.[9] Adams et al. (2020) found bidirectional causality between energy use and carbon emissions and a unidirectional causality between economic policy uncertainty and carbon emissions.[10] Adedoyin et al. (2020) emphasized that economic policy uncertainty has a one-way impact on CO_2 emissions, and that there is a two-way causal relationship between energy consumption and economic growth.[11]

Region-specific investigations have elucidated the intricate connections between energy consumption, carbon emissions, and economic growth across diverse domains. Adewuyi et al. (2017), Ahmad et al. (2016), Ahmed et al. (2022), Akadiri et al. (2022), and Akadiri et al. (2019) meticulously explored these dynamics within the contexts of West Africa, India, and other relevant regions.[12] Akpan et al. (2012) specifically discerned the interrelationships between electricity consumption, carbon emissions, and economic growth in Nigeria.[13]

Ali et al. (2023) focused on emerging markets in Asia and showed the dynamic relationship between renewable and non-renewable energy consumption, economic growth, and CO_2 emissions.[14] While Ali et al. (2021) tested the environmental Kuznets curve hypothesis by studying Pakistan and examining the effects of fossil energy consumption, economic development, and foreign direct investment on

CO_2 emissions.[15] Al-Mulali (2014), Al-Mulali et al. (2012), Andreoni et al. (2012), and Alshehry et al. (2015) examine the impact of energy use and carbon emissions on economic growth in various regions, including Sub-Saharan Africa, Italy, and Saudi Arabia.[16]

A plethora of comprehensive studies has extensively investigated a wide range of scenarios, imparting invaluable insights. Researchers such as Ang (2008), Antonakakis et al. (2017), Anwar et al. (2020), Ardakani et al. (2019), Arouri et al. (2012), Asafu-Adjaye (2000), Asumadu-Sarkodie et al. (2017), and others have diligently explored the intricate interdependencies among energy consumption, carbon emissions, and economic growth in countries including Malaysia, Far East Asian countries, Middle Eastern and North African countries, as well as Senegal.[17] Furthermore, Audi et al. (2016), Awodumi et al. (2020), Aye and Edoja (2017), Ayres et al. (2010), Banday et al. (2019, 2020), and several other researchers have scrutinized these dynamics within Lebanon's oil-producing regions, various manufacturing economies, diverse global regions, and specific countries.[18] Moreover, notable contributions from studies by Begum et al. (2015), Bekhet et al. (2013, 2017), Benali et al. (2020), Bhat (2018), Boukhelkhal (2022), Bozkurt et al. (2014), and others have provided significant insights into these relationships in countries such as Singapore, GCC countries, emerging markets, Africa, Turkey, and Malaysia.[19] Additionally, a multitude of research endeavors carried out in France, Turkey, the MENA region, BRICS countries, globally encompassing analyses, Bangladesh, Lebanon, Pakistan, and various other regions and countries have significantly contributed to our comprehension of the complex interactions among the variables of interest (Fei et al., 2011; Cowan et al., 2014; Ghosh et al., 2014; Can et al., 2016; Haseeb et al., 2017; Danish et al., 2018; Gorus et al., 2019; Fan et al., 2020; El Menyari, 2021; Chen et al., 2022; Chen et al., 2023).[20]

Additionally, the relationship between energy consumption, carbon emissions, and economic growth has also been investigated in specific countries. Ocal et al. (2013) and Ozturk et al. (2010) examined this relationship in Turkey, Odhiambo (2009) explored it in Tanzania, Odhiambo (2012) focused on South Africa, and Odugbesan et al. (2020) studied the MINT countries (Mexico, Indonesia, Nigeria, and Turkey).[21] Ohlan (2015) examined the nexus in India, while Omri (2013, 2014) focused on Middle East and North Africa (MENA) countries.[22] Ozcan et al. (2020) explored the relationship in OECD countries.[23]

Studies focused on specific regions or countries include Rahman et al. (2022) and Rahman (2020) in Bangladesh, Rahman et al. (2020) in South Asia, and Rahman et al. (2021) in emerging economies (NICs).[24] Raihan et al. (2022) explored Peru, and Rasoulinezhad et al. (2018) focused on the Commonwealth of Independent States, while Raza et al. (2019) investigated the relationship in the United States and studied the impact of the three variables in different sectors.[25] Peng et al. (2020), Saboori et al. (2014), and Tamba (2017) studied the transport sector, while

Raihan et al. (2022) focused on the agricultural sector and Zhang et al. (2021) studied the tourism sector.[26]

Moreover, researchers explored the role of additional factors in shaping the relationship between energy use, carbon emissions, and economic growth. Salman et al. (2019) investigated the impact of institutional quality, while Vasylieva et al. (2019) explored the role of corruption.[27] Sufyanullah et al. (2021) focused on the impact of globalization, Zafar et al. (2022) studied the effects of urbanization, and Ziaei (2015) studied the effects of financial development.[28]

Taken together, these scientific studies have greatly enhanced our understanding of the complex interplay between energy use, carbon emissions, and economic growth in different countries and regions.

3. *Model and Methodology*

Theoretical Framework — Unit Root Tests: This paper builds upon theoretical frameworks used in prior studies to examine the relationship between energy consumption, economic growth, and CO_2 emissions. To explore this causal relationship, we conducted tests for stationarity of the series using the augmented Dickey-Fuller (1979-1981)[29] and Phillips-Perron (PP) tests. Perron (1988, 1989)[30] proposed a unit root test that allows for structural breaks, considering three alternative models: the crash model, which involves a shift in the intercept; the changing growth model, which involves a change in the slope; and the model with changes in both the intercept and slope.

Previous investigations have highlighted that conventional unit root tests do not provide sufficient evidence to reject the unit root hypothesis for series exhibiting trend stationarity with a structural break. Conversely, the Perron (1989) test has faced criticism due to its assumption of exogeneity regarding the time of the break, meaning that the timing of the break is known beforehand. To address this limitation, Zivot et al. (1992)[31] made significant advancements to the Perron unit root tests by incorporating endogeneity in the consideration of the breakpoint (TB).

To examine the presence of a unit root against the alternative of a trend stationarity process with a structural break in slope and intercept, we utilized the following regression model:

$$\text{Ln}\, GDP_t = \beta_0 + \beta_1 \ln EC_t + \beta_2 \ln CO_{2t} + \varepsilon_t$$

$$\text{Ln}\, EC_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln CO_{2t} + \varepsilon_t$$

$$\text{Ln}\, CO_{2t} = \theta_0 + \theta_1 \ln GDP_t + \theta_2 \ln EC_t + \varepsilon_t$$

Where, $Ln\ GDP_t$ is the logarithm of GDP per capita, $Ln\ EC_t$ the logarithm of energy consumption per capita, and $Ln\ CO_{2t}$ the logarithm of CO_2 emissions per capita.

The significance of testing for stationarity lies in the fact that non-stationary series regression can lead to inefficient coefficients and forecasts, as well as invalid significance tests (Granger, 1969).[32] In contrast, stationary time series exhibit regression of integration, where the mean and variance remain constant over time. To assess the presence of a unit root, we employed either the Dickey-Fuller Simple or Augmented Test (Dickey and Fuller, 1979-1981) or the Phillips-Perron Test (1988), depending on the presence of homoscedastic or heteroscedastic variances, respectively.[33]

Theoretical Framework — Cointegration Analysis within a VAR Framework: The methodology employed in this study involved several steps to examine the long-run relationship between the variables. Initially, the stationarity of the data was tested to ensure the suitability of applying cointegration analysis. Subsequently, the Johansen cointegration test was conducted within a Vector Autoregressive (VAR) framework. The VAR model is based on a system of delayed equations, where each variable acts as both an explanatory and an explained variable. The optimal delay order (P) for the VAR model was determined through the minimization of the Akaike criterion. Furthermore, the Engle-Granger test statistics were employed to identify the rank of the matrix capturing the cointegration relationships among the selected variables. Specifically, considering two stationary time series, denoted as x_t and y_t, the VAR(P) model can be represented as follows:

$$x_t = \alpha_1 + \sum_{j=1}^{P} \beta_{1,j} x_{t-j} + \sum_{j=1}^{P} \gamma_{1,j} y_{t-j} + \varepsilon_{1,t}$$

$$y_t = \alpha_2 + \sum_{j=1}^{P} \beta_{2,j} x_{t-j} + \sum_{j=1}^{P} \gamma_{2,j} y_{t-j} + \varepsilon_{2,t}$$

$(\alpha_i,\ \beta_{i,j},\ \gamma_{i,j})$ represent the parameters of the VAR(P) and $\varepsilon_{i,t}$ the innovations that follow an i.i.d. process. $(0, \sigma_\varepsilon^2)$ with i = 1, 2 and j = 1 … .P.

Theoretical Framework — Granger Causality Test: In order to analyze the causality among variables, we employed a vector error correction model. This model allowed us to estimate the lagged error correction terms (ECT_{t-1}) derived from the long-run co-integration relationship, indicating the presence of co-integration among the variables. Granger (1969) defined causality as the ability of variable y_t is included in x_t.[34] Using a VAR model, we tested the hypothesis that y_t does not cause x_t by imposing restrictions on its parameters, such as $\gamma_{1,1} = \gamma_{1,2} = \gamma_{1,P} = 0$. This hypothesis was examined using statistical tests such as the Fisher, Wald, or Likelihood-Ratio test. Additionally, we also investigated the inverse relationship, i.e., whether x_t does not cause y_t, by testing if $\beta_{1,1} = \beta_{1,2} = \beta_{1,P} = 0$.

Theoretical Framework — Sims Causality Test: Sims (1980) presents a slightly different specification of the test, considering that if the future values of y_{1t}

can explain the present values of y_{2t}, then y_{2t} is the cause of y_{1t}.[35] This is a Fisher test of coefficient nullity. This is represented by the following expression:

$$y_{1t} = a_1^0 + \sum_{i=1}^{P} a_{1i}^1 y_{1t-i} + \sum_{i=1}^{P} a_{1i}^2 y_{2t-i} + \sum_{i=1}^{P} b_i^2 y_{2t+i} + \varepsilon_{1,t}$$

$$y_{2t} = a_2^0 + \sum_{i=1}^{P} a_{2i}^1 y_{1t-i} + \sum_{i=1}^{P} a_{2i}^2 y_{2t-i} + \sum_{i=1}^{P} b_i^1 y_{1t+i} + \varepsilon_{2,t}$$

y_{1t} does not cause y_{2t} if the following hypothesis is accepted H0: $b_1^2 = b_2^2 = \ldots = b_p^2 = 0$

y_{2t} does not cause y_{1t} if the following hypothesis is accepted H0: $b_1^1 = b_2^1 = \ldots = b_p^1 = 0$

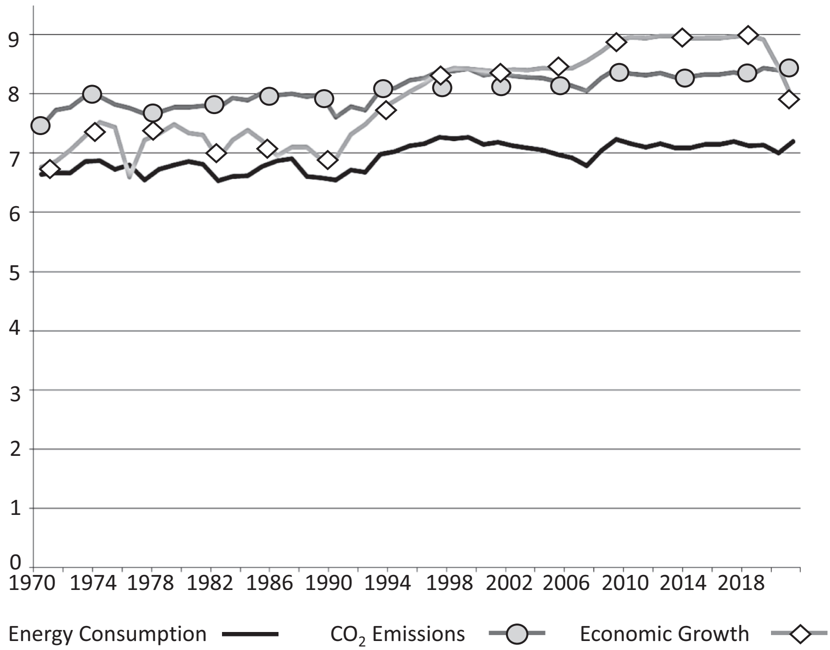
Data and Variables: This study used the annual time series data of the Lebanon economy from 1970-2021. Annual data used in this study includes GDP per capita, energy consumption per capita, and CO_2 emissions per capita. In this study, we measure the annual GDP per capita in U.S. dollar (constant prices) and CO_2 emissions per capita in metric tons and the energy consumption per capita in kilograms of oil equivalent (kgep). The data of this study are collected from World Bank Database. All the variables used in natural logarithms to address the problem of heteroscedasticity and reduce the differences between variables related to differences in their units of measurement (Rahman et al., 2020; Lee, 2006; Coondoo, 2002).[36]

Figure 1 presents the time plots of GDP, the energy consumption, and the CO_2 emissions in Lebanon for the period 1970-2021. Visual inspection of the graph indicates positive correlation between the three series. Lebanon is confronted with multiple challenges in the near future due to its heavy reliance on energy imports, inadequate capacity to meet domestic electricity needs, escalating global prices, and the persistent pressure on developing nations to adopt binding obligations for CO_2 emissions reduction. To effectively address these challenges, it becomes crucial to gain a comprehensive understanding of the causal connections among energy consumption, economic growth, and CO_2 emissions. Such understanding will facilitate the development and implementation of appropriate national energy and environmental policies.

4. *Empirical Results*

Unit Root Tests: The Philips-Perron (PP) unit root was considered more appropriate to address the heteroscedasticity exclusion. As observed in Table 1, the results demonstrated that all the variables were non-stationary at constant and trend assumptions but became stationary at the first difference. Hence, it can be

Figure 1
THE VARIATION OF ENERGY, GROWTH, AND TRANSITION IN LEBANON OVER TIME FROM 1970-2021 (LOG)



concluded that the variables of log GDP per capita, energy consumption per capita, and CO_2 emissions per capita are not stationary. Additionally, the null hypothesis of a unit root is rejected for all series when examining their first differences.

Cointegration Tests: Once we have verified that our variables are integrated at the same first order, we proceed to conduct Johansen's cointegration test. This test utilizes the Trace and Max-Eigen Statistics to examine whether there is a long-term equilibrium among logEC, logGDP, and $logCO_2$, indicating their cointegration. The Trace test's null hypothesis states that there are, at most, r cointegration relationships, while the alternative hypothesis suggests there are more than r relationships. On the other hand, the Max-Eigen test's null hypothesis assumes exactly r cointegration relationships, while the alternative hypothesis proposes $r + 1$ relationships.

The accuracy of the Johansen cointegration test depends on the determination of the number of lags. We select this number using the Akaike information criterion (AIC), Schwarz information criterion (SBC), and Hannan-Quinn (HQ) information criterion. The result indicates that the chosen number of lags is P=2. These findings are presented in Table 2.

Table 1
PHILLIPS-PERRON UNIT-ROOT TEST RESULTS[a]

	Philips-Perron			
	Constant and trend		First Difference	
Variables	T-Statistic	Prob.	T-Statistic	Prob.
lnEC	−1.2355	(0.8921)	−6.0029***	(0.000)
lnGDP	−3.0643	(0.1258)	−8.3083***	(0.000)
lnCO_2	−3.4519	(0.0558)	−8.6708***	(0.000)

[a]*, **, and *** indicates 1%, 5%, and 10%, respectively, while lag selection is based on automatic Schwarz Info Criterion (SIC). Abbreviations: lnEC = log of energy consumption per capita; lnGDP = log of gross domestic product per capita; and lnCO_2 = log of CO_2 emissions per capita.

In Table 2, each line represents a null hypothesis, denoted as $r = \{0, 1, 2\}$, along with the corresponding Trace and Max-Eigen statistics and their critical values. If the Trace or Max-Eigen statistic exceeds the critical value at the 5-percent threshold, the null hypothesis is rejected. In this case, the null hypothesis suggesting a cointegration rank of $r = 0$ is rejected at the 5-percent threshold. Therefore, we cannot reject the null hypothesis that $r = 1$, indicating a cointegration rank of 1.

Long-Run Adjustment Analysis: After conducting cointegration tests, we proceeded with the estimation of Vector Error Correction Model (VECM) to analyze the short-term relationships and assess the speed of long-run adjustment. The VECM allows us to examine both the direction and intensity of these relationships.

Table 2
JOHANSEN COINTEGRATION TEST: TRACE STATISTIC AND MAX-EIGEN STATISTIC[a]

	Trace statistic	Max-Eigen statistic
Null Hypothesis		
***r* = 0**	83.3780* 0.000 [35.0109]	83.3780* 0.000 [35.0109]
***r* = 1**	83.3780* 0.000 [35.0109]	83.3780* 0.000 [35.0109]
***r* = 2**	83.3780* 0.000 [35.0109]	83.3780* 0.000 [35.0109]

[a]Trace test indicates 3 cointegrating equations at the 0.05 level using the trace statistic and 3 cointegration equations using the Max-Eigen statistic; * denotes rejection of the hypothesis at 0.05 level; ** Mackinnon-Haug-Michelis(1999) p-values.

Our findings reveal significant long-term causal relationships between the variables. The coefficient for CO_2 is negative and statistically significant ($p < 0.05$), indicating an inverse relationship between CO_2 emissions and the GDP growth. Similarly, energy consumption exhibits a negative and significant relationship ($p < 0.05$). These results highlight the importance of endogenous variables (CO_2 and EC) in the adjustment process when the system deviates from its equilibrium state.

Table 3 presents the estimated long-term adjustment factors. The coefficient for CO_2 emission per capita indicates an annual adjustment speed of 0.734 percent, suggesting a gradual reduction in emissions over time. Likewise, energy consumption demonstrates an annual adjustment speed of 0.301 percent. These figures provide insights into the rate at which the variables converge towards their long-run equilibrium.

Overall, our analysis reveals significant long-term relationships and emphasizes the role of CO_2 emissions and energy consumption in the adjustment process. The estimated adjustment speeds further contribute to our understanding of the dynamics among the variables over the long term.

Short-Run Analysis: Based on the findings presented in Table 4, the variable being examined is the GDP growth. The error correction term is both negative and statistically significant, indicating the presence of a long-term equilibrium relationship. Among the variables considered, only CO_2 with a lag of one period shows statistical significance. This suggests that when CO_2 with a one-period lag increases, there is a corresponding decrease in GDP growth, as indicated by the negative coefficient associated with this variable.

Based on the findings presented in Table 5, the variable under examination is CO_2. The CO_2 variable with a one-period lag is found to be negative and statistically significant, indicating that an increase in CO_2 emissions in the previous period is associated with a decrease in the current CO_2 levels. Additionally, the variable representing energy consumption (EC) with a two-period lag shows a positive and statistically significant relationship. This suggests that an increase in energy consumption two periods ago is associated with a subsequent increase in CO_2 emissions.

Based on the findings presented in Table 6, the variable being examined is energy consumption (EC). The error correction term is positive and statistically

Table 3

VECTOR ERROR CORRECTION ESTIMATIONS: LONG-RUN ADJUSTMENT[a]

Variable	Coefficient	Standard Error	t-statistic
lnGDPD(−1)	1.000	N/A	N/A
$lnCO_2$ (−1)	−0.734*	0.150	−4.888
lnEC(−1)	−0.301*	0.082	−3.648

[a]*denotes statistical significance at $p < 0.05$.

Table 4
VECTOR ERROR CORRECTION ESTIMATIONS: EMPIRICAL RESULT OF SHORT-RUN TAKING GDP GROWTH AS DEPENDENT VARIABLE[a]

Variable	Coefficient	Standard Error	t-statistic
CointEQ1	−1.325	0.435	−3.04
GDP (−1)	0.339	0.317	1.06
GDP (−2)	0.014	0.223	0.063
CO_2 (−1)	−0.850*	0.309	−2.752
CO_2 (−2)	0.036	0.256	0.144
EC (−1)	−0.147	0.128	−1.152
EC (−2)	−0.051	0.088	−0.590
c	−0.0003	0.002	−0.111
R-squared			0.545
Adj. R-squared			0.465

[a]*denotes statistical significance at $p < 0.05$.

significant, suggesting the existence of a long-term equilibrium relationship among the variables. Furthermore, the variable representing GDP with a two-period lag is found to be negative and statistically significant. This implies that a decrease in GDP two periods ago is associated with a subsequent decrease in energy consumption.

Furthermore, the observation that the adjusted R-squared is lower than the R-squared suggests that the inclusion of further independent variables in the model may not substantially enhance its ability to explain the variation in the dependent variable.

Table 5
VECTOR ERROR CORRECTION ESTIMATIONS: EMPIRICAL RESULT OF SHORT-RUN TAKING CO_2 AS INDEPENDENT VARIABLE[a]

Variable	Coefficient	Standard Error	t-statistic
CointEQ1	0.459	0.347	1.323
GDP (−1)	−0.346	0.252	−1.371
GDP (−2)	−0.122	0.178	−0.689
CO_2 (−1)	−0.512*	0.246	−2.080
CO_2 (−2)	0.013	0.020	0.063
EC (−1)	0.188	0.102	1.844
EC (−2)	0.170*	0.070	2.426
c	−0.0002	0.002	−0.128
R squared			0.561
Adj. R-squared			0.484

[a]*denotes statistical significance at $p < 0.05$.

Table 6
VECTOR ERROR CORRECTION ESTIMATIONS: EMPIRICAL RESULT OF SHORT-RUN TAKING ENERGY CONSUMPTION AS INDEPENDENT VARIABLE[a]

Variable	Coefficient	Standard Error	t-statistic
CointEQ1	1.999*	0.781	2.558
GDP (−1)	−0.521	0.568	−0.917
GDP (−2)	−0.839*	0.400	−2.094
CO_2 (−1)	0.402	0.553	0.726
CO_2 (−2)	0.860	0.459	1.873
EC (−1)	−0.058	0.229	−0.254
EC (−2)	−0.197	0.157	−1.252
c	−0.002	0.005	−0.412
R-squared			0.467
Adj. R-squared			0.373

[a]*denotes statistical significance at $p < 0.05$.

Granger Causality: Our aim in conducting the Granger Causality analysis was to determine the directional relationship between GDP growth, CO_2 emissions, and energy consumption in Lebanon. The findings presented in Table 7 reveal a significant unidirectional relationship between energy consumption and GDP growth. This is supported by the probability value of 0.0503, which is close to the conventional significance level of 0.05. As a result, we can reject the null hypothesis and conclude that there is evidence of a Granger causality relationship from energy consumption to GDP growth.

Sims Causality: The objective of our study was also to employ Sims Causality analysis to ascertain the causal directionality between GDP growth, CO_2 emissions, and energy consumption in Lebanon. The outcomes reported in Table 8 reveal a statistically significant bidirectional causality relation between economic growth and the other variables. This assertion is substantiated by the calculated probability

Table 7
GRANGER CAUSALITY TEST[a]

Null Hypothesis	Obs	F-statistic	Probability (p-value)
EC does not Granger Cause CO_2	49	2.339	0.108
CO_2 does not Granger Cause EC		0.036	0.964
GDP does not Granger Cause CO_2	49	0.218	0.804
CO_2 does not Granger Cause GDP		2.354	0.106
GDP does not Granger Cause EC	49	2.412	0.101
EC does not Granger Cause GDP		**3.201****	**0.05**

[a]*, **, and *** indicate the level of significance at 10%, 5%, and 1%, respectively.

Table 8
SIMS CAUSALITY TEST

Null Hypothesis	Obs	F-statistic	Fisher value
EC does not Sims Cause CO_2	49	**15.81**	**4.05**
CO_2 does not Sims Cause EC		2.87	4.05
GDP does not Sims Cause CO_2	49	**16.36**	**4.05**
CO_2 does not Sims Cause GDP		**14.01**	**4.05**
GDP does not Sims Cause EC	49	**8.29**	**4.05**
EC does not Sims Cause GDP		**17.30**	**4.05**

value of 0.0503, which approximates the conventional significance level of 0.05. Moreover, we are able to reject the null hypothesis and establish that there exists empirical support for a Sims unidirectional relationship from energy consumption to CO_2 emissions.

Test Validation: The Granger analysis of causality conducted on Lebanese data demonstrates a singular unidirectional causal link, where energy consumption influences economic growth. Energy consumption plays a dominant role in driving economic growth, both directly in the production process and indirectly as a complement to labor and capital. In this context, energy is considered as an additional factor of production alongside the traditional factors of capital and labor. As noted by Yu (1985), Tsani (2010), Belke (2011), and Destek (2016), the implementation of energy policy affects the level of production.[37]

Examining the relationship between energy consumption (EC) and CO_2 emissions, the historical analysis based on Granger causality indicates no significant association between these two variables. However, an anticipation analysis utilizing the Sims test reveals a unidirectional causality from energy consumption to CO_2 emissions. This implies that the present values of energy consumption can explain the future values of CO_2 emissions, indicating that the increase in CO_2 emissions is a consequence of excessive energy consumption. Consequently, it is advisable for the Lebanese government to prioritize renewable energy sources to mitigate the environmental impact.

In terms of the association between GDP and CO_2 emissions, the historical analysis employing Granger causality fails to reveal any significant relationship between these two variables. However, a predictive investigation utilizing the Sims test demonstrates a bidirectional connection between GDP and CO_2 emissions. This implies that the increase in CO_2 emissions is a consequence of rising GDP, and conversely, GDP growth is influenced by CO_2 emissions. Hence, it underscores the importance of implementing renewable energy sources within industries and manufacturing sectors in Lebanon to mitigate CO_2 emissions while simultaneously promoting GDP growth.

Table 9
SUMMARY CAUSALITY TESTS

Null Hypothesis	Obs	Granger	Sims
EC does not Cause CO_2	49	NO	**YES**
CO_2 does not Cause EC		NO	NO
GDP does not Cause CO_2	49	NO	**YES**
CO_2 does not Cause GDP		NO	**YES**
GDP does not Cause EC	49	NO	**YES**
EC does not Cause GDP		**YES**	**YES**

When examining the relationship between energy consumption (EC) and GDP growth, it is evident that both the Granger causality analysis and the Sims test validate the influence of EC on GDP growth. The Granger causality analysis establishes a unidirectional causality, indicating that changes in EC lead to subsequent changes in GDP growth. This suggests that energy consumption is a crucial driver of economic expansion. Additionally, the Sims test further expands our understanding by revealing a bidirectional relationship between EC and GDP. This implies that not only does energy consumption affect GDP growth, but GDP growth also reciprocally influences energy consumption. The interdependence between these two factors highlights the intricate dynamics at play within the energy and economic systems.

In summary, based on the Vector Error Correction Model (VECM) analysis, we can deduce that both energy consumption (EC) and CO_2 emissions have a long-term impact on GDP growth in Lebanon. Energy consumption plays a fundamental role in reducing CO_2 emissions and stimulating GDP growth. It is crucial for Lebanese authorities to exercise conscious energy consumption practices and recognize the significance of EC in the economic cycle.

5. *Conclusion*

Lebanon, a country nestled in the eastern Mediterranean region, finds itself facing a challenging and complex economic and environmental landscape. The nation has been grappling with a series of socio-political and economic crises that have significantly impacted its overall development trajectory. As Lebanon navigates through these turbulent times, it is essential to examine key indicators such as GDP, energy consumption, and CO_2 emissions to gain a deeper understanding of the current situation. Given the intricate relationship between GDP, energy consumption, and CO_2 emissions, it becomes evident that addressing these challenges necessitates a comprehensive and integrated approach.

The utilization of the Granger approach to analyze causality patterns in Lebanese data provides compelling evidence of a robust unidirectional causal relationship. Specifically, it establishes that energy consumption wields a significant and influential role in driving economic growth. The impact of energy consumption on economic expansion is twofold: it directly contributes to the production process and functions indirectly as a complementary factor to both labor and capital. In this analytical framework, energy assumes a notable position as an additional factor of production, alongside the traditionally recognized factors of labor and capital. This recognition underscores the intricate interdependence of these factors in shaping economic outcomes.

Our findings provide valuable insights for policymakers and stakeholders, emphasizing the need to develop and implement effective energy policies that account for the intricate dynamics between energy consumption, labor, capital, and overall economic outcomes. By doing so, it is possible to harness the potential of energy as a catalyst for sustainable and robust economic development in Lebanon.

The meticulous examination of the relationship between energy consumption (EC) and CO_2 emissions reveals intriguing insights. Employing the Granger causality approach, the historical analysis fails to provide substantial evidence indicating a significant association between these variables. However, employing a forward-looking perspective through the Sims test, a unidirectional causal connection emerges, specifically from energy consumption to CO_2 emissions. This noteworthy finding indicates that current energy consumption levels possess the capacity to shed light on future CO_2 emission patterns, suggesting that the observed increase in CO_2 emissions primarily stems from excessive energy consumption.

The implications of these findings are substantial and warrant attention. It is strongly advised that the Lebanese government gives utmost priority to the adoption of renewable energy sources. This strategic shift towards renewable energy not only helps mitigate the adverse environmental impact associated with CO_2 emissions but also cultivates a sustainable and environmentally friendly energy sector. By embracing alternative and renewable energy sources, Lebanon can take significant strides towards achieving its environmental objectives while concurrently contributing to global endeavors aimed at combating climate change. This transformative step not only promotes ecological balance but also paves the way for a more resilient and prosperous future.

Thorough investigation of the association between GDP and CO_2 emissions, employing the rigorous Granger causality approach, fails to reveal substantial evidence of a significant relationship between these variables based on historical analysis. However, a forward-looking and anticipatory investigation using the Sims test uncovers a noteworthy bidirectional connection between GDP and CO_2 emissions. This insightful finding suggests that the increase in CO_2 emissions is a direct consequence of the expanding GDP, and conversely, the magnitude of GDP growth is influenced by the level of CO_2 emissions.

Our findings underline the paramount importance of integrating renewable energy sources within the industrial and manufacturing sectors in Lebanon. By adopting this approach, it becomes possible to effectively mitigate CO_2 emissions while simultaneously fostering GDP growth. This strategic shift aligns harmoniously with the overarching sustainable development goals, facilitating the transition towards a greener and more resilient economy. By embracing renewable energy sources, Lebanon can actively contribute to global efforts aimed at addressing climate change and promoting environmental sustainability. This transformative approach not only mitigates the adverse environmental impact of CO_2 emissions but also enhances the long-term economic prospects of the nation. It creates an environment conducive to sustainable growth, enabling Lebanon to achieve a harmonious balance between economic progress and environmental stewardship.

The relationship between energy consumption (EC) and GDP growth reveals compelling evidence from both the Granger causality analysis and the Sims test, supporting the significant impact of EC on GDP growth. The Granger causality analysis establishes a unidirectional causality, illuminating that changes in EC lead to subsequent changes in GDP growth. This finding underscores the pivotal role played by energy consumption as a fundamental driver of economic expansion. Moreover, the Sims test enhances our understanding by unveiling a bidirectional relationship between EC and GDP. This signifies that not only does energy consumption exert an influence on GDP growth, but reciprocally, GDP growth also influences energy consumption. The interconnectedness between these two factors accentuates the intricate dynamics within the energy and economic systems.

Our results shed light on the mutual influence and interdependence between energy consumption and GDP growth. They emphasize the complex relationship and underscore the necessity of comprehensively understanding the underlying dynamics. By gaining a comprehensive understanding of these dynamics, policymakers can make informed decisions regarding energy policies, thereby fostering sustainable economic growth and ensuring the efficient allocation of resources within the energy sector. Such informed policy decisions can pave the way for a more resilient and prosperous economic future.

Against this backdrop, it is imperative to explore innovative solutions, leverage international collaborations, and engage in concerted efforts to ensure the sustainable development of Lebanon's economy while mitigating its environmental impact. By doing so, Lebanon can strive towards achieving an appropriate balance between economic growth, energy consumption, and environmental preservation, ultimately paving the way for a prosperous and sustainable future.

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