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THE INFLUENCE OF RENEWABLE ENERGY AND FINANCIAL DEVELOPMENT ON TESTING THE ENVIRONMENTAL KUZNETS CURVE IN LEBANON: ARDL APPROACH

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Abstract

This study considers the impacts of financial development and the consumption of renewable energy in Lebanon for the period 1990–2021, employing the Environmental Kuznets Curve. The financial sector in Lebanon is considered a major engine in the economic development. Green energy sources and environmental protection are taking higher importance nowadays with the increase of implications for climate change and global warming worldwide. This paper examines the Environmental Kuznets Curve's presence and implications for Lebanon's financial development and renewable energy consumption. The econometric model used annual data from the World Development Indicators. Utilizing the autoregressive distributed lag (ARDL) technique, both near- and long-term relationships were estimated. The findings support the Environmental Kuznets Curve hypothesis and show that energy consumption and real income have a statistically significant beneficial effect on carbon emissions and that their square has a statistically significant negative impact on carbon emissions over the long and short term. The results show variations in signs for financial development between the short and long term and stable results for renewable energy with negative signs in both terms. These results show the importance of further research on the influence of financial development and green energy consumption on EKC. Therefore, policymakers need to pay more attention to these variables for a sustainable economy that is facing the effects of climate change.

Keywords Environmental Kuznets Curve, renewable energy consumption, financial development

JEL Classification O44, O47, Q56

INTRODUCTION

There is a paradoxical connection between the quality of the environment and the sustainability of economic expansion. Theoretically, the Environmental Kuznets Curve (EKC) states that carbon emissions rise in tandem with income until a certain threshold before they start to decrease. A growing number of academics and policymakers have started to take an interest in the EKC. It was initially presented by Kuznets (1955), who proposed an opposite U-shaped correlation between economic expansion and income inequality. Nowadays, carbon dioxide (CO2) is one of the most hazardous and widely released gases from economic activity. Moreover, it contributes significantly to the deterioration of the ecosystem (Perez-Suarez & Lopez-Menendez, 2015). Ecological sustainability and economic development are desired in this trade-off, with the goal of limiting environmental deterioration during economic expansion.

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According to Beckerman (1992), economic expansion will almost certainly lead to environmental improvement. Businesses and customers alter their manufacturing and consumption habits to favor more environmentally friendly products. In this way, income development might not be the cause of environmental degradation but rather one of its solutions. A nation's economic level is not the sole factor that determines its carbon emissions; other significant contributors include energy use, international trade, and financial development (Ozturk & Acaravci, 2013; Zhang, 2011). The example in this paper is Lebanon, a rising Middle Eastern nation with a complicated economic structure and varying degrees of financial development. The World Bank (2024) reports that Lebanon has grown its emissions of carbon dioxide, faces declining key per capita water supplies, and is vulnerable to climate variability on multiple fronts.

Since ecological concerns are starting to appear on the main public policy agenda in Lebanon, it is becoming increasingly vital to understand how economic and financial development affects environmental circumstances. It is crucial to investigate the Lebanese economy's financial and economic trends in relation to ecological sustainability; the atmospheric buildup of pollutants due to economic activities results in global warming (Andreoni & Galmarini, 2016).

The EKC further details the connection between environmental quality and economic expansion. More specifically, this concept explains that to a certain tipping point for income disparity, environmental degradation increases with economic progress, after which it declines, and a U-shaped inversion curve is reached (Grossman & Krueger, 1995). This connection holds that environmental deterioration has an economic growth component as well as an issue. With this solution in hand, numerous scholars looked at the question of whether economic expansion can address environmental issues in various nations and areas (Raggad, 2018; Bekhet & Othman, 2018).

1. LITERATURE REVIEW AND HYPOTHESES

The issue of environmental pollution and economic growth has already gotten a lot of attention. The theory of the Environmental Kuznets Curve (EKC) is considered the basis for many empirical investigations. The EKC framework emphasizes how crucial energy use is to generate the country's GDP and assumes that environmental degradation and real income have an inverse U-shaped relationship. First, environmental degradation is rising with the national income. Nonetheless, it is anticipated that pollution will reduce after a given threshold of national economic development (Kuznets, 1955).

The EKC goes into further detail about the connection between environmental quality and economic expansion. More specifically, this concept demonstrates how, up to a specific income level, environmental deterioration rises with economic progress and income inequality tipping point, after which it declines and an inversed U-shaped curve is reached (Grossman & Krueger, 1995). This connection holds that environmental deterioration has an economic growth component as well as an issue. With this solution in hand, numerous scholars looked at the question of whether economic expansion can address environmental issues in various nations and areas (Shahbaz et al., 2017; Raggad, 2018; Bekhet & Othman, 2018).

The EKC hypothesis was only partially explored in the first phase of empirical research, with the goal of characterizing and explaining environmental pollution primarily in terms of economic considerations, including several proxies for economic growth (Onafowora & Owoye, 2014; P. Narayan & S. Narayan, 2010; Poudel et al., 2009; Akbostanci et al., 2009; Grossman & Krueger, 1995). The second wave of research differs in that it takes a more in-depth approach while accounting for the structural issue. In other words, these studies look for extra or structural elements that could exacerbate or speed up the process of environmental contamination. According to the EKC hypothesis, the quality of the environment deteriorates in the first level of economic expansion. However, as the real income increases, environmental quality begins to improve beyond a certain point. The EKC presence in the BRICS economies was investigated by Haseeb et al. (2018), considering the influence of energy usage, globalization, financial development, urbanization, and economic expansion. In the BRICS economies, they verified the presence of bidirectional causality and the EKC hypothesis. Pata (2018) used the ARDL approach in Turkey to assess the existence of EKC with financial development, renewable energy consumption, and urbanization. The analysis backs up the EKC theory; it demonstrates the inverse U-shaped correlation between economic expansion and CO2 emissions.

Nonetheless, there is disagreement among scholars on the validity of the EKC hypothesis. While certain literary strands find little evidence to support the EKC hypothesis, others contend considerable clues. For instance, Tutulmaz (2015) contends that Turkey can use the EKC theory. The presence of the EKC in broken-down data for Malaysia is supported by Saboori and Sulaiman (2013). Baek (2015) discovers less proof of maintaining the validity of the EKC concept in Arctic nations. Research shows evidence supporting the N-shaped curve in some articles and the inverted U-shaped curve in others. In six of the eight nations examined, Onafowora and Owoye (2014) discovered an N-shaped trajectory; just two showed the indication of an inversed U-shaped curve. This ambiguity could stem from overall pollution being used as a stand-in for environmental degradation while ignoring variations in the economy's emissions structure (Stern, 2004).

Fan and Zheng (2013) did not discover any evidence in the Sichuan Province of China to support the EKC hypothesis. The variations in econometrics methods, data spans, and country-specific features could be the cause of the disparities in these empirical conclusions. Using the ARDL bounds test approach, Koc and Bulus (2020) looked at the existence of EKC as having an influence on trade openness and renewable energy usage in South Korea. The data do not support the EKC theory in Korea. Using the EKC hypothesis concept, Bibi and Jamil (2021) looked into the connection between economic expansion and air pollution in six different regions. Every investigated region supports the EKC, with the exception of Sub-Saharan Africa, indicating that different regions have different correlations with the EKC. According to Ozturk and Acaravci (2013) and Zhang (2011), there are other factors besides a country's income level that affect its carbon emissions; other significant sources of emissions include financial development, energy consumption, and international trade. Numerous research studies have examined the relationship between carbon emissions and financial development, contending that the former positively affects the latter. Numerous pathways by which financial liberalization might be detrimental to environmental quality have been found.

According to Zhang (2011), financial development in China is a significant predictor of rising carbon emissions. However, Ozturk and Acaravci (2013) contended that there is no appreciable correlation between CO2 and an indicator of financial development in Turkey. In the meantime, Jalil and Feridun (2011) suggested that financial development could lower energy consumption and carbon emissions by improving business performance and energy efficiency. The results of Boutabba (2014) for India support the idea that environmental quality declines as financial growth increases. Using the EKC paradigm, Khan and Ozturk (2021) looked into how financial development affected environmental pollution in a few emerging nations. The panel of economies shows that financial advancement mitigates the detrimental influence of income on CO2 emissions through indirect channels, supporting the existence of EKC.

Charfeddine and Khediri (2016) examined the connections between CO2 emissions, economic expansion, financial development, trade openness, and power consumption in the United Arab Emirates. The findings attest to EKC's existence. Furthermore, they discovered a reverse nonlinear correlation between CO2 emissions and economic expansion. Akca (2021) used the EKC hypothesis to investigate how Turkey's CO2 emissions were affected by financial development and economic expansion. The EKC approach is valid in Turkey during the relevant era based on the long- and short-term findings. Nevertheless, financial progress and CO2 emissions hold no statistically significant correlation.

Ahmad et al. (2024) investigated how financial development, technical innovation, and energy efficiency all have an impact on CO2 emissions in

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developing Asian regions. The primary conclusions show that positive shocks to financial development generally cause it to conform to the EKC's U-shaped assumptions. Taher (2020) investigated how financial development and economic expansion affected environmental deterioration in Lebanon. The studied variables had a considerable beneficial influence on CO2 as a proxy for environmental degradation.

As per Alam et al. (2012), Pao and Tsai (2010), Acaravci and Ozturk (2010), Soytas and Sari (2009), Shahbaz et al. (2015), and Saboori and Sulaiman (2013), environmental deterioration is largely caused by energy consumption. These studies support energy-induced EKC for both industrialized and developing nations. However, because different econometric methodologies were employed in some of the studies, the results are not always consistent. An increasing amount of empirical research has examined the connection between income and environmental quality, with the theory being that as more energy-efficient technology and efficient infrastructure are incorporated into national development processes, the relationship may turn negative (De Bruyn et al., 1998; Esteve & Tamarit, 2012; Coondoo & Dinda, 2008; Managi & Jena, 2008; Friedl & Getzner, 2003).

In order to reduce the bias caused by missing data, some empirical research includes a number of extra proxies that are used to account for shifts in the global environment and globalization processes. Testing the EKC has recently focused more attention on the importance of modifications to the terms of international trade and energy pricing. International trade has increased because of globalization and trade liberalization, which has increased overall output and raised environmental pollution (El-Aasar & Hanafy, 2018). Additionally, empirical studies on the EKC for developing and developed nations can be separated.

Even though empirical studies verifying the EKC assumptions are widespread nowadays, the outcomes have produced contradictory results. Ozatac et al. (2017) investigate the EKC in Turkey, considering aspects like trade, urbanization, energy use, and financial advancement. The results show the presence of long-term correlations between the variables and EKC in Turkey.

Using the ARDL approach, Zambrano-Monserrate et al. (2018) give empirical data for Singapore from 1971 to 2011 that confirm the EKC hypothesis. Financial development, trade openness, economic growth, energy consumption, and population density are the causal variables of environmental deterioration. According to Moghadam and Dehbashi (2018), financial development hastens environmental deterioration; conversely, more trade openness lessens environmental harm in Iran. Moreover, the outcomes in Iran contradicted the EKC concept.

Various scholars have examined this problem with different economic stakeholders in order to quantify its environmental impact. Dogan and Turkekul (2016) examine how environmental deterioration is impacted by commerce, energy, financial development, and urbanization. Using ARDL, they conclude that although trade benefits the US economy, energy use and urbanization contribute to environmental damage. Bekhet and Othman (2018) present the reversed N-shaped EKC in Malaysia's instance and renewable energy use. Like this, Sinha and Shahbaz (2018) considered energy generation and consumption in India. Using ARDL, they discover a negative connection and an EKC with an inversed U form between CO2 and the production of renewable energy.

Numerous studies include population density, foreign direct investment (FDI), domestic investment, and financial development in the EKC model. Considering that, an economy must ascertain the veracity of the EKC theory to implement the appropriate controls on environmental deterioration. Extant literature lacks solid evidence since the EKC hypothesis is valid in certain countries but not in others. For instance, EKC is found to be valid for Croatia, the United Arab Emirates, and Singapore by Ahmad et al. (2017), Charfeddine and Khediri (2016), and Zambrano-Monserrate et al. (2018). Se. Katircioglu and Sa. Katircioglu (2018) and Gill et al. (2018) confirm the validity of EKC assumptions in Malaysia and Turkey. Recent studies have shown that Pakistan's environmental degradations are positively impacted both short- and long-term natural gas, coal, and oil usage and economic growth (Khan et al., 2019). Pakistan should also promote renewable energy to treat environmental degradation.

In a related vein, Khan et al. (2019) incorporated globalization into this exchange. Their results using the dynamic ARDL demonstrate that financial development, trade, FDI, globalization, and energy consumption all have a favorable effect on Pakistan's carbon emissions. On the other hand, their empirical research shows that FDI, trade, and innovation have a negative influence on CO2 in the short term.

Regarding Lebanon, there is no current literature on the effect of financial development and renewable energy on the EKC theory. Thus, the purpose of this study is to determine whether the EKC link between economic growth, renewable energy, and financial development holds true. On the one hand, environmental limitations could result in less growth than is required. On the other hand, improved growth and sustainability trends may result from new opportunities and advantages brought about by financial development. Taking these things into account, this study has two goals. The first is to confirm that EKC exists in Lebanon regarding carbon dioxide. The second goal is to comprehend the short- and long-term relationships between financial development, renewable energy, real income, and CO2 emissions. Accordingly, the hypotheses are as follows:

H1: *Real income positively influences CO2 emissions with a negative sign for its square.*

H2: *Financial development influences the EKC and has a favorable impact on CO2.*

H3: *Renewable energy influences EKC with a negative influence on CO2.*

2. METHOD

The EKC is an empirical link between environmental quality and economic expansion. Due to the variation in environmental quality parameters, econometrics techniques, observation duration, and nations, there is an abundance of research on EKC validity. Several empirical articles addressing the EKC issue in all its manifestations have been found. Grossman and Krueger (1995) verified the applicability of the EKC technique. J. Kraft and A. Kraft (1978) and Soytas and Sari (2009) examined the connection between income, CO2 emission intensity, and energy intensity. There is no theory that explains EKC because it is an empirical relationship. Considering the inconsistent outcomes from the EKC hypothesis that were previously covered, this study investigates the relationship between CO2 emissions, financial development, and renewable energy consumption within the context of the EKC framework in Lebanon. To examine the effects of these financial and economic indicators on environmental quality, the study considers the variables of income, financial development, renewable energy consumption, and trade openness as control variables:

$$CO2 = f(GDP, GDP^2, FD, REC, TRD). \quad (1)$$

where CO2 emissions (CO2), real GDP per capita (GDP) and its square (GDP^2), financial development (FD), renewal energy consumption (REC), and trade openness (TRD). CO2 and GDP are transformed into natural logarithm in accordance with the body of current research (Sinha & Shahbaz, 2018; Zambrano-Monserrate et al., 2018; Bekhet & Othman, 2018) in order to achieve direct elasticity and dependable and consistent results. As recommended by Ozturk and Acaravci (2013), Haseeb et al. (2018), and Ahmad et al. (2024), a log-linear econometric model has been employed for CO2 and GDP:

$$lCO2_t = \alpha_0 + \alpha_1 lGDPt + \alpha_2 lGDP^2 + \alpha_3 fd_t + \alpha_4 rec + \alpha_5 trd + \varepsilon_t. \quad (2)$$

where GDP per capita as a proxy for real income is measured in constant 2015 US dollars (*GDP*); carbon emissions are measured as CO2 emissions in kt (*CO2*); Financial development (*fd*) is calculated using an IMF financial development index, and renewable energy consumption is expressed as a percentage of total final energy consumption (REC); trade openness is measured as trade per GDP (*trd*).

Based on EKC hypothesis, the study seeks to evaluate the short- and long-term links between carbon emissions and their drivers. In the Lebanon scenario, the variables for the years 1990–2020 are real income, financial development, and renewable energy consumption. The investigation uses

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yearly data from the databases of the International Monetary Funds (IMF, 2024) and World Development Indicators (World Bank, 2024).

a_2 is supposed to have a negative sign, a_1 is expected to have a positive sign to validate the EKC hypothesis. The EKC's inverted U-shaped pattern indicates that, up to a certain point, per capita carbon emissions and per capita income increase simultaneously before declining. The link between per capita income and CO2 emissions is monotonically growing if a_3 is statistically negligible. Depending on the country's level of financial development, the indications of a_3 might be either positive or negative. Since a higher level of energy consumption raises CO2, which in turn boosts economic activity in the nation, this study anticipates a_4 to be positive.

3. RESULTS AND DISCUSSION

This study has employed the cointegration autoregressive distributed lag method (ARDL), as proposed by Pesaran et al. (2001). Compared to previous cointegration techniques, this strategy has the following advantages. It can be used for variables that are I(0), I(1), or combined. Secondly, when looking for cointegration, it captures the dynamics over both the short and long terms. Moreover, rather than assuming that a unique cointegration vector exists, it provides explicit tests for its presence. In small samples, it is preferred. Pesaran and Shin (1999) said that endogeneity and serial correlation issues are addressed by the proper lag selection in the ARDL methodology.

Considering the EKC's economic vulnerability (Stern, 2004; Tamazian et al., 2009), the ARDL bounds testing method is used. Compared to earlier cointegration systems like those of Johansen and Juselius (1990) and Engle and Granger (1987), the ARDL methodology offers a few advantages. The fact that ARDL can be used regardless of integration level, with the exception of I, is one of the major advantages. Second, the Johansen and Juselius cointegration technique is less effective in small samples than the ARDL procedure (Pesaran & Shin, 1998). Third, even in the case of endogenous regressors, ARDL yields reliable *t*-statistics and objective long-run coefficients (Boutabba, 2014). Fourth, as Laurenceson and Chai (2003) explained, ARDL includes sufficient lags to fully capture the process of creating data for a given modeling system.

The ARDL test model starts with descriptive statistics, followed by checking the stationarity tests and lags determinants. The second step is the model determination through a bound test to verify the long-term and short-term link and cointegration between variables and to check the EKC validity. The last group of tests is for model diagnosis through autocorrelation, heteroskedasticity, normality, and stability tests.

Carbon emissions in Lebanon showed variation over the years with a growth trend due to the weak regulations, as shown in Figure 1. However, it showed a slit decrease after 2019 due to the COVID-19 pandemic. The Lebanese economic growth has grown all over the years (Figure 2a). However, it showed a massive decline after 2019

Source: World Bank (2024).

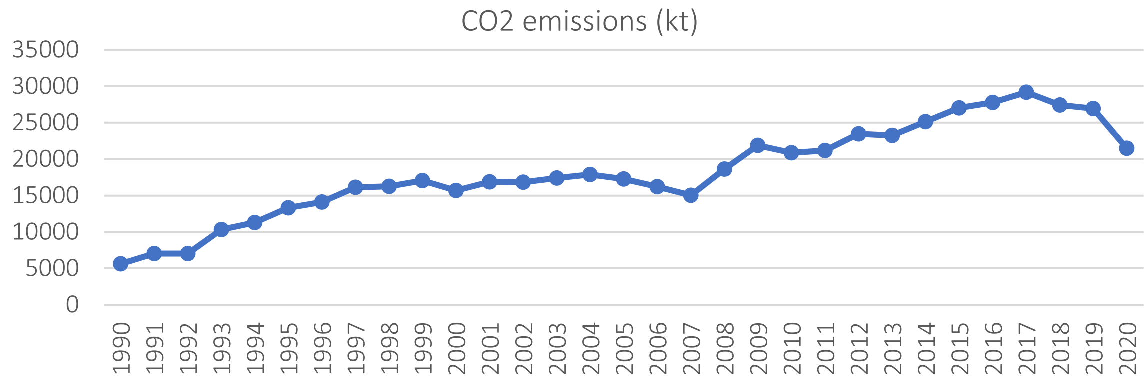

Figure 1. CO2 emissions variation

Source: World Bank (2024) and IMF (2024).

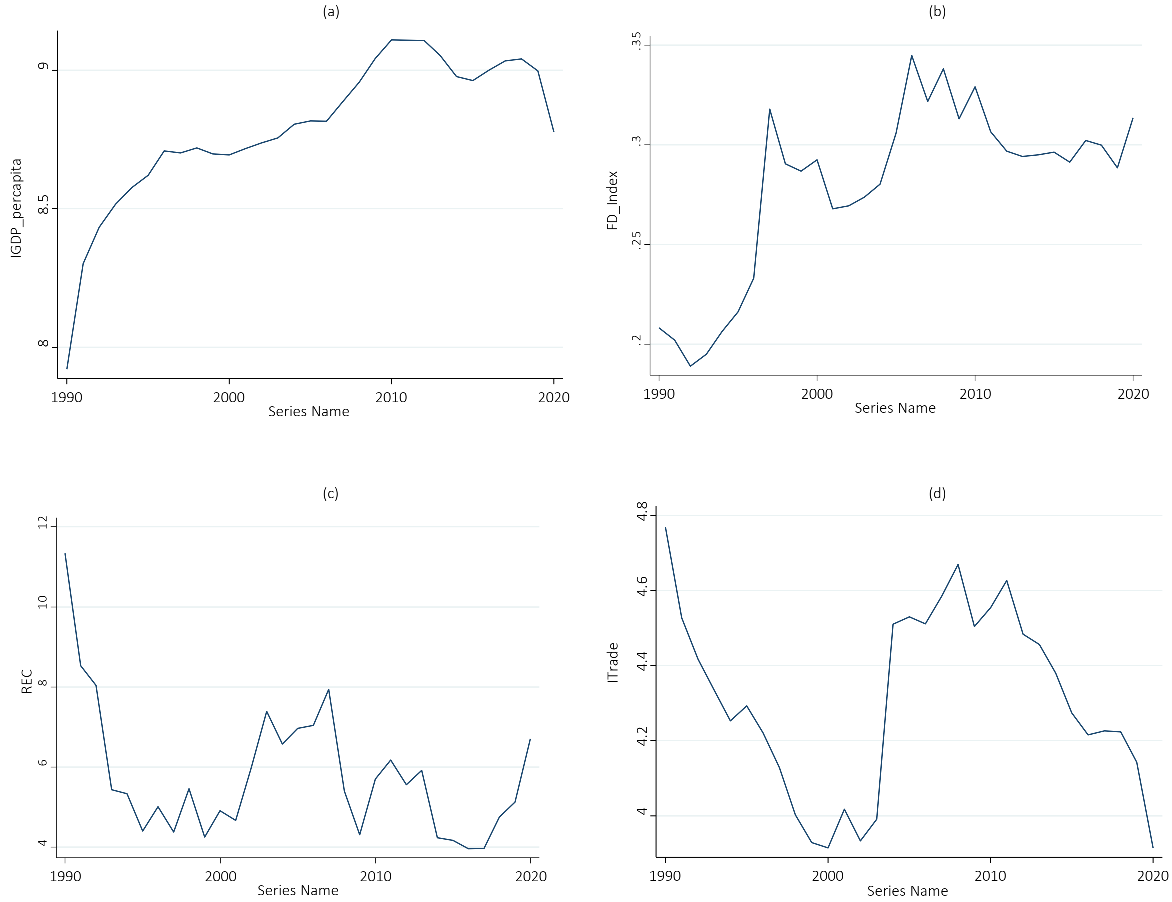

Figure 2. Variation of GDP, FD Index, renewal energy consumption, and trade openness in Lebanon over time

as a reflection of the economic and financial crisis. The Lebanese financial development is considered always the main support for the Lebanese economy, disregarding the last financial crisis. Renewal energy consumption showed instability in the trend, which reflects the absence of strategy, which showed a remarkable increase after 2019. This is mainly caused by the COVID-19 pandemic and the Lebanese economic crisis that affected the availability of fuel in the country. Trade openness show a clear decline after 2010, which is the period of the Syrian war that is considered the main importer and the transit country for the Lebanese economy (IMF, 2023).

The phenomenon of stationarity in a series is important because it has an impact on the series' behavior. If X and Y are two non-stationary series, then regressing X on Y in equation 3 will provide an illogical or deceptive regression (Yule, 1926). A unit root indicates that the series is non-stationary.

$$Yt = \beta 0 + \beta 1 Xt + \varepsilon t. \quad (3)$$

A series is deemed stationary if it does not have a unit root. In determining whether it is autoregressive, the stationarity test's objective is for the model to have a unit root. The unit root test is employed to ascertain the order of the variables' integration. The stationarity of the provided series has been tested by the enhanced Dickey-Fuller test (ADF).

The application of common unit root tests to every single series, at first difference every series is stationary I (1) apart from renewal energy consumption was integrated at I (0) at the 5% significance level. The outcomes are shown in Table 1.

According to Stock and Watson's (1993) proposal, the amount of lag orders has an impact on the ARDL models' sensitivity for lag determina-

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Table 1. Unit root tests

Variable	Series			Series in first difference		p-value
	Test statistic	Dickey-Fuller	P-value	Test statistic	Dickey-Fuller	
Ln(CO2emissions (kt))	–2.384	–3.580	0.3881	–4.517	–2.989	< 0.001
Ln (GDP)	–3.344	–3.580	0.059	–4.203	–2.989	< 0.001
Ln (GDP2)	–2.905	–3.580	0.161	–3.747	–2.989	0.004
FD Index	–1.993	–3.580	0.605	–6.064	–2.989	< 0.001
REC	–4.295	–2.986	< 0.001	–	–	–
Trade openness	–2.193	–2.986	0.2087	–4.871	–2.989	< 0.001

Note: Dickey-Fuller critical value (5%).

tion. The paper selected the model with the lowest number of Schwartz Information Criteria (SBIC) and Hannan Quinn Information Criteria (HQIC) values.

Table 2. Optimal lags

Lag	HQIC	SBIC
0	–0.340	–0.145
1	–8.049*	–6.689*
2	–7.951	–5.425

Note: * is the optimal lag.

In Table 2, the first column's lag count, as well as the ideal lag factors, such as HQIC and SBIC, are visible. According to Table 2, the ideal lag is 1 since it displays the greatest lag that may be employed with the HQIC and SBIC.

ARDL model estimation starts with the ARDL bounds cointegration test. This test takes into account *H0:* no cointegrating equation and *H1*: *H0* is false. Table 3 presents the test to see if the explanatory and explained variables have a longer-term association.

Table 3. Bounds test

F equals to 7.376; T equals to –4.928 Finite sample: 30 observations, 4 short-run coefficients, 5 variables								
–	10%	–	5%	–	1%	–	p-value	–
–	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
F	2.600	4.001	3.207	4.836	4.747	6.939	0.001	0.007
t	–2.504	–3.811	–2.895	–4.291	–3.716	–5.301	0.001	0.018

Note: H0: no level relationship; do not reject *H0*: If the values of *F* or *t* for I(0) variables are nearer zero than the critical values. Alternatively, if the target level for I(0) variables is reached by either *p*-value, reject *H0* under the following scenarios: either both *p*-values for I(1) variables are less than the acceptable level, or both *F* and *t* are more extreme than critical values.

Table 4. ARDL long- and short-run results

Regression model ARDL(1,1,1,1,1,0); Adj R-squared = 0.8859 R-squared = 0.9252; Sample: 1991–2020; total observations: 30 Log Likelihood = 58.162095; Root MSE = 0.0386 Durbin-Watson = 2.568423						
D.lCO2kt	Coef.	Std. err.	t	P> | t |	[95% conf. interval]	
ADJ						
lCO2kt L1.	–.4587671	.0930931	–4.93	0.000	–.6536133	–.263921
LR						
LGDP	43.68427	12.37161	3.53	0.002	17.79019	69.57835
LGDP2	–2.348822	.6963695	–3.37	0.003	–3.80634	–.8913036
FD	–1.941343	.9267712	–2.09	0.050	–3.881097	–.0015885
REC	–.0075527	.0284608	–0.27	0.794	–.0671219	.0520165
Trade	–.0087298	.0023653	–3.69	0.002	–.0136804	–.0037792
SR						
LGDP D1.	8.250078	4.390799	1.88	0.076	–.9399696	17.44013
LGDP2D1.	–.4558508	.2534408	–1.80	0.088	–.9863084	.0746069
FD D1.	.807056	.4054819	1.99	0.061	–.0416274	1.655739
REC D1.	–.0591385	.0128563	–4.60	0.000	–.086047	–.03223
_cons	–87.84038	29.77535	–2.95	0.008	–150.1609	–25.51985

According to the bound test results shown in Table 3, the *F* and *t* statistics are less than the *F* and *t* critical values at 5% and 10%. Therefore, the test results disprove Pesaran et al. (2001)'s null hypothesis. Both the independent and dependent variables have a long-term relationship. Thus, the model validates the longer-period connection (Kripfganz & Schneider, 2020). Table 4 shows the ARDL long- and short-run results.

Table 4 shows that if GDP per capita increases by 1% over time, then on average, CO2 upsurges by 43.68%. Furthermore, if GDP2, FD Index, and trade openness upsurge by 1%, CO2 declines on average by 2.35%, 1.94%, and 0.009%, respectively. However, LGDP, LGDP2, FD, and trade openness coefficients are significant when their corresponding *p*-values have less than 5% statistical significance.

The output ADJ section reports a negative speed-of-adjustment coefficient of –0.4587671. It gauges how rapidly an equilibrium distortion is corrected, or, put another way, how much of a deviation from the equilibrium relationship the dependent variable reacts in a given time. Table 4 results are expressed in equation 4.

$$\begin{aligned}\Delta lCO2kt &= -87.84 - 0.459(lCO2kt_{t-1} \\ &-43.68 \cdot LGDP\_percapita \\ &+2.35 \cdot LGDP\_percapita2 \\ &+1.94 \cdot FD\_Index + 0.008 \cdot REC \\ &+0.009 \cdot Trade)\ 8.25 \cdot \Delta LGDP\_percapita \\ &-\ 0.456 \cdot \Delta LGDP\_percapita_2 \\ &+\ 0.807 \cdot \Delta FD\_Index - 0.059 \cdot \Delta REC\ .\end{aligned} \tag{4}$$

Model diagnosis starts with checking the autocorrelation test, heteroscedasticity test, normality test, and model stability by structural break test.

The basic autocorrelation test are Durban Watson and Breusch-Godfrey LM test that are employed in this model diagnosis. First, the Durbin-Watson d-statistic equals 2.568423, close to 2; therefore, it shows no autocorrelation (Table 5).

The Breusch-Godfrey LM test results in Table 5 show that the *p*-values are greater than 0.05; thus, it proves no autocorrelation (Breusch & Godfrey, 1986).

Table 5. Breusch-Godfrey LM test for autocorrelation

Lags(p)	F	df	Prob > F
1	3.468	(1, 18)	0.0790
2	2.462	(2, 17)	0.1151
3	3.164	(3, 16)	0.0533
4	2.487	(4, 15)	0.0879
H0: no serial correlation			

Table 6. Heteroscedasticity white test

Chi 2(29) = 30.00; Prob is greater than chi 2 = 0.4140			
Source	**Chi 2**	**df**	**p**
Heteroskedasticity	30.00	29	0.4140
Skewness	7.51	10	0.6764
Kurtosis	0.28	1	0.5984
Total	37.79	40	0.5702

Note: H0: Homoskedasticity; *Ha:* Unrestricted heteroskedasticity.

Table 6 demonstrates that *p*-values are higher than 0.05. Therefore, the residuals of the estimated model are randomly distributed (Cameron & Trivedi, 2013).

Table 7. Shapiro-Wilk W test for normal data

Variable	Obs	W	V	z	Prob > z
Resid	30	0.97684	0.736	–0.634	0.73682

Table 7 demonstrates that the *p*-value is 0.737, which is higher than 0.05. The test result fails to reject the null hypothesis; therefore, the residuals are normally distributed (Shapiro & Wilk, 1972).

Structural break tests determine when and whether the model has seen a major modification test data (*H0:* No break vs. *H1:* break).

Table 8. Cumulative sum test for parameter stability

Statistic	Test statistics	1% Critical Value	5% Critical Value	10% Critical Value
recursive	0.4409	1.143	0.9479	0.850

The test statistic is 0.441, which is less than 1% and 5% as critical values. As a result, the null hypothesis cannot be rejected.

Estimating the model's stability is the last stage of the ARDL process. According to Brown et al.

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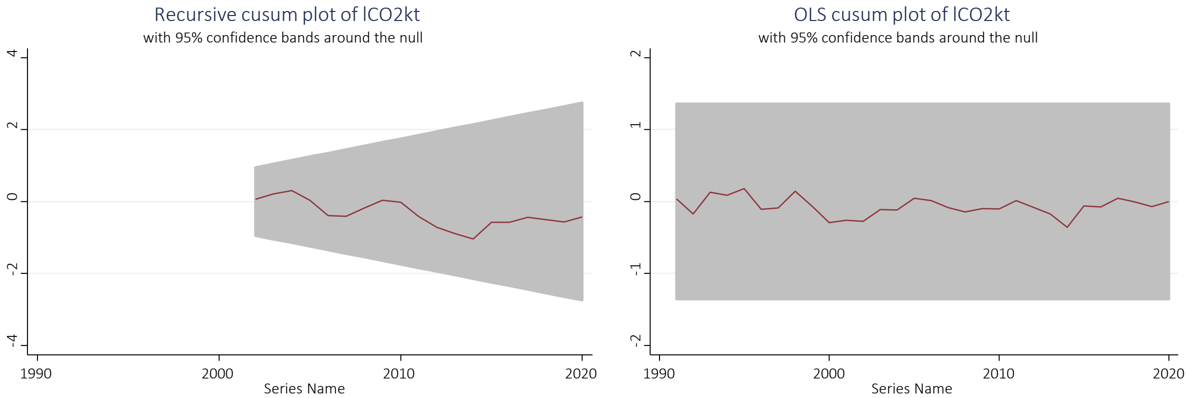

Figure 3. CUSUM test

(1975), the cumulative (CUSUM) and cumulative sum of squares (CUSUMSQ) stability tests are used to verify the stability of the model. The plots of the CUSUM and CUSUMSQ statistics, as displayed in Figure 3, reveal how stable the developed model is, situated inside the 5% significant critical bounds.

The model diagnosis evaluation affirms that the EKC theory is validated: in the instance of Lebanon, a U-shaped inverse connection is present between real income and CO2 emissions (Kuznets, 1995; Grossman & Krueger, 1995; Shahbaz et al., 2017; Raggad, 2018; Bekhet & Othman, 2018). These results confirm *H1*.

The study also checked the influence of financial development on CO2 emissions with real income as EKC. The results show detrimental effects over time but beneficial effects in the near term. These outcomes support Zhang (2011) and Ozturk and Acaravci (2013) for the long run, and Taher (2020) and Ahmad et al. (2024) for the short run. This variation in Lebanon is due to the sensitivity of this sector to any unstable situations. Therefore, the second research hypothesis is confirmed only in the short run.

Renewable energy negatively affects CO2 emissions, which is in accordance with Acaravci and Ozturk (2010), Alam et al. (2012), Khan et al. (2019), and Saboori and Sulaiman (2013). The results confirm *H3*.

CONCLUSION

Using data for the years 1990–2020, this study investigates the validity of the EKC hypothesis and the link between CO2 emissions and their primary causes in Lebanon, namely renewable energy consumption and financial development. Additionally, the study checks whether financial development and renewable energy significantly influence Lebanon's environmental quality. This study uses the ARDL bounds test to estimate the long-run and short-run associations.

The bound test findings indicate that the *F* and *t*-statistic are smaller than the critical values of *F* and *t* at 5% and 10%. As a result, the test results reject the null hypothesis. The independent variables and the dependent variable have a long-term relationship. Thus, the model validates the longer-period relationship. The findings demonstrate the cointegration of the sampled variables and a long-term relationship in Lebanon, linking the use of renewable energy, real income, financial development, and CO2 emissions. The short and long-run relationship estimation results show that the real income and its square coefficients support the EKC theory in Lebanon and allow for the assumption that financial developments and the use of renewable energy have a major influence on the degradation of the environment.

Further empirical findings support the significance of the financial sector as a short-term source of environmental pollution in Lebanon. CO2 emissions in Lebanon are positively impacted by both the long- and short-term forecasts of real income, financial development, and renewable energy consumption. However, financial development positively affects CO2 emissions in the short run but negatively in the long run.

The current study provides evidence in favor of the EKC hypothesis presented by Kuznets (1995) in Lebanon by supporting an inverted U-shaped relationship between CO2 emissions, real income, financial development, and renewable energy consumption. Furthermore, statistically significant predictors that explain environmental degradation in Lebanon are the country's financial development and energy use. Considering these conclusions, Lebanese authorities must implement environmentally friendly policies to ensure sustainable economic growth. Therefore, policies related to renewable energy consumption and financial development must be in line with initiatives to slow down environmental damage in Lebanon.

AUTHOR CONTRIBUTIONS

Conceptualization: Hanadi Taher.
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Methodology: Hanadi Taher.
Resources: Hanadi Taher.
Software: Hanadi Taher.
Validation: Hanadi Taher.
Writing – original draft: Hanadi Taher.
Writing – review & editing: Hanadi Taher.

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