Globalization, Energy Mix, Renewable Energy, and Emission: Romanian Case

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Abstract

Europe reaffirmed its commitment to become world first climate-neutral continent by 2050. Eastern European countries should pursue these renewable sources as a policy priority in order to cope with this target. In Eastern Europe, the transition to renewable energy sources was slow. Adopting tight regulations in this region in order to comply with the environmental European requirements benefited of important exemptions in time. In this study, we aim to investigate the existence of the Environmental Kuznets Curve in Romania and its shape during 1990-2019, based on an ARDL model with short-run and long-run estimations, considering total energy consumption, renewable energy share, FDI and trade openness. Findings suggest a U-shaped curve, a positive linkage between total energy consumption or FDI and CO2 emissions/capita in the long-run, a negative relation between renewable energy share of total energy mix and emissions, and a negative relation between trade openness and CO2 emissions/capita. Based on these findings, some policy recommendations can be designed to stimulate the renewable energy usage and trade openness in Romania for decreasing CO2 emissions.

Keywords: EKC, FDI, renewable energy, total energy consumption, trade openness,

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1. Introduction

The economic growth - environment link represents a major issue for achieving the sustainable development goals, because the intense economic activity generates significant environmental problems that can negatively affect the achievement of sustainable development (Bongers, 2020). Environmental degradation and pollution have been noticed in all countries, all over the world, and greatly impact the ecosystem (Sannigrahi *et al*., 2020). The Environmental Kuznets Curve (EKC) which states a non-linear link, U-inversed

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shaped between environment pollution and a country's income has gained the attention of many researchers over time (Caviglia-Harris *et al.*, 2009).

For fighting the environmental problems, without negatively affecting the economic prosperity and wellbeing it is important to properly analyse and understand the impact of the economic growth on the environmental pollution. Until recently, the researchers that have focused on EKC have analysed the nexus between economic growth - total energy consumption - CO2 emissions. The empirical studies on EKC provide very different results, since the results depend on the used dataset, the considered pollution indicators, or the applied econometric methodology. As all the studies provided a strong and clear evidence for the positive relation between the fossil fuel energy consumption and pollution, the focus shifted toward the use of the renewable energy. Therefore, more recent studies examined the nexus renewable energy consumption - economic growth - pollutant emissions. So, the classical EKC was revised as R-EKC (Renewable Environmental Kuznetz Curve) (Yao *et al.*, 2019).

A consensus for EKC hypothesis couldn't be reached among researchers, but when renewable energy was analysed in the frame of EKC hypothesis, the results were more homogenous, and a uni-directional running from economic growth to renewable energy consumption was found. More recent studies have investigated the relationship between economic growth and the consumption of renewable energy (Apergis and Payne, 2012; Tugcu *et al.*, 2012). They have demonstrated the major impact of renewable energy on emissions without deteriorating economic growth. Apergis and Payne (2012) demonstrated the existence of a bidirectional causality between renewable energy consumption and economic growth that supports the idea of increasing the consumption of the renewable energy for achieving economic growth, without harming the environment. Tugcu *et al.* (2012) made a comparison between renewable and non-renewable energy sources in order to decide which type of energy is more important for economic growth in the G7 countries. The authors conclude that bidirectional feedback hypothesis between renewable and non-renewable energy and economic growth has been supported. According to these results, we can agree on the major role of renewable energy in the increase of GDP and in protecting the environment. Paramati *et al.* (2017) proved in their study that renewable energy generation is very important for achieving the sustainable economic development.

CO2 represents 76% of the total gas emissions (IPPC, 2014); therefore, many studies investigated the impact of the economic activity of the environment based on this indicator (Atasoy, 2017; Sinha and Shahbaz, 2018; Hu *et al.*, 2019). An excessive CO2 concentration leads to global warming. The concentration of CO2 has especially increased as a result of the industrial revolution, transportation, deforestation, population growth and exponential growth in manufacturing activities around the world. According to the most recent data from the Global Carbon Project (2019), the top five carbon emitter countries are China, the U.S., India, Russia, and Japan. According to Balaguer and Cantavella (2018), in the EKC studies, the estimates of GDP coefficients have been questioned and they can be improved by adding more explanatory variable for CO2 emissions.

The aim of the current research is to investigate the EKC in relation with the renewable energy consumption and total energy consumption in Romania, adding FDI and trade openness as control variables, given the major role of FDI and trade in the economic context and especially for a developing country such as Romania. In the CEE region, Romania displays the highest share of renewable energy consumption in the energy mix, after Croatia, but the CO2 emissions didn't decrease as much as for the other CEE countries against 1990 (according to the Eurostat database in 2018). Romania has also attracted a high share of FDI during the 2000's, but Romania ranks on the last position among CEE countries according to the share of the GDP/capita of the EU average (Eurostat database). So, we aim to investigate the relation between energy consumption, FDI, trade openness, GDP and CO2 emissions in Romania so we can elaborate some adequate policy recommendations based on the results of the empirical analysis performed for the entire period after 1990 until 2019. In the rest of the paper, first, the literature review and previous studies will be reviewed, then the methodology, and results and discussion will be presented. Finally, conclusions and policy recommendations will be presented.

2. Literature review

There are many studies focused on EKC that analysed panels of countries or individual countries, including total energy consumption or only renewable energy consumption, with very mixed results regarding the shape of EKC. Jalil and Mahmud (2009) examined the long-run relationship between carbon emissions, energy consumption and income in China during 1975–2005. ARDL methodology was applied, and the results validated the EKC relationship. The results of Granger causality tests indicated a uni-directional causality from economic growth to CO2 emissions. The results of this study also indicated that the pollution is determined by income and energy consumption in the long run. Acaravci and Ozturk (2010) investigated the causal relationship between CO2 emissions, energy consumption and economic growth using an ARDL approach in the European countries during 1960-2005. EKC was validated only for Italy. Ang (2007) examined the dynamic causal relationships between per capita CO2 emissions and GDP in France. His results show the existence of long-run causality running from economic growth to the increase of CO2 emissions. The inverted U-shaped EKC hypothesis is verified. Haggar (2012) investigated Canadian industrial sectors and found that energy consumption has a major positive impact on pollution and an inverted U-shaped EKC was validated.

Jaunky (2011) has studied EKC hypothesis for 36 high-income countries during 1980–2005. The empirical analysis for individual countries validated EKC only in United Kingdom. However, it can be observed a positive relationship between GDP and CO2 emissions for the whole panel and a uni-directional causality running from GDP to CO2 emissions.

The inverted U-shaped relationship between GDP and pollution has been validated by some other authors for large panels of countries (Leitão, 2010; Shafiei and Salim, 2014; Ahmed *et al.*, 2016; Al-Mulali *et al.*, 2016; You *et al.*, 2015). Lee *et al.* (2009) have found an inverted U-shaped EKC when using a quadratic model and an N-shaped EKC when using a cubic model. Churchill *et al.* (2018) found an N-shaped EKC in Australia, Canada and Japan, but not in Italy, while Shahbaz *et al.* (2017) found a U-shaped inverted EKG in Germany. A N-shaped EKC was found for China and India (Pal and Mitra, 2017), but an exponential increase of pollution as a result of income growth in Brasil (Soberon and D'Hers, 2020). Khan *et al.* (2016) found a linear relationship between economic growth and CO2 emissions in the developed economies. Same findings were achieved by Liddle and Messinis (2016) or Mazzanti and Musolesi (2013) that demonstrated a linear increasing relationship between economic growth and CO2 emissions for advanced economies.

López-Menéndez *et al.* (2014) found an inverted U-shaped EKC for EU27 countries with more than 20% of the country's electricity generated from renewable energy sources, but a N-shaped trend for the EU27 countries where less than 20% of the country's electricity is generated from renewable energy sources during 1996-2010. Other authors found an increasing trend of CO2 emissions in 74 countries and contradicted the entire existence of a U-shaped or inverted U-shaped EKC (Permann and Stern, 2003; Özokcu and Özdemir, 2017). Some other authors demonstrated that the inverted U-shaped EKC is not validated in high-income countries, but the use of renewable energy decreases CO2 emissions in all the analysed countries, no matter their development level (De Jesus *et al*., 2020). Erdogan *et al.* (2020) using an AMG approach demonstrated that EKG is invalid for OECD countries during 1990-2014 based on an energy-mix analysis, but applying FMOLS and DOLS approaches that don't cope with cross-sectional dependence, the EKC was validated. However, they found a negative relation between renewable energy and CO2 emissions.

Harbaugh *et al.* (2002) or Effiong and Oriabije (2018) also found no evidence that this relationship is validated. Dogan and Ozturk (2017) also observe that the EKC model is not valid in the United States from 1980 through 2014, using both renewable and non-renewable energy into their model with structural breaks. A possible explanation for such differences in testing EKC hypothesis could be represented by the fact that most of these studies didn't consider the heterogeneity of countries due to economic, social, political or structural differences that can impact differently on the environment (Dinda, 2004; Purcel 2020) or they used standard panel techniques without checking the cross-sectional dependence which is essential or the robustness of the results (Apergis *et al*., 2017).

Jebli *et al.* (2013) analysed the causal relationship between CO2 emissions, GDP and renewable energy consumption, for a panel of 25 OECD countries during 1980-2009. They showed the existence of a uni-directional causality running from GDP per capita to CO2 emissions. FMOLS and DOLS results suggest that GDP have a positive impact on CO2 emissions, while square of per capita GDP and per capita renewable energy consumption have a negative impact on per capita CO2 emissions. The U-inverted shape is demonstrated. So, using the renewable energy is efficient to fight against global warming and climate change.

Lopez-Menendez *et al.* (2014) examined 27 EU countries using a panel data during 1996-2010 and proved the existence of an extended EKC, based on an analysis which includes the renewable energy as explanatory variable for CO2 emissions. They have found a decreasing trend of CO2 emissions for Italy, Germany, UK or France. Other studies (Cole and Elliot, 2003; Álvarez-Herranz and Balsalobre-Lorente 2016; Allard *et al*., 2018) proved a N-shaped EKC for 74 countries during 1994-2012 introducing the renewable energy consumption into the quantile regressions and institutional quality index (except for upper-middle income countries). They also shown a negative relation between renewable energy and CO2 emissions proving the significance of the renewable energy use in fighting the pollution ad global warming (Allard *et al*., 2018). Jahanger *et al.* (2022a) by using the FMOLS approach and considering renewable energy as a control variable in 69 developing countries from 1990 to 2018 revealed the negative linkage between renewable energy and CO2 emission. Usman and Balsalobre-Lorente (2022) in a study in newly industrialized countries from 1990 to 2019 using the AMG model indicated the improved effect of renewable energy on environmental quality.

Yao *et al.* (2019) proved in their study that the EKC and R-EKC are validated for 17 major developing and developed economies during 1990-2014 based on FMOLS and DOLS estimations and the turning point of R-EKC takes place before the turning point of EKC for those countries, meaning that the renewable energy accelerates the reduction of the CO2 emissions. Pao and Chen (2019) verified R-EKG for G20 countries based on a P-OLS and VECM analysis during 1991-2016. Sharif *et al.* (2019) also validated R-EKC for 74 top carbon emitter countries in the world, based on FMOLS estimations. Balezentis *et al.* (2019) also verified R-EKC for EU countries during 1995-2005 based on FMOLS and DOLS estimations, Baek (2016) validated R-EKC for USA using an ARDL approach, Dong *et al.* (2018) achieved the same results for China, Sinha and Shahbaz (2018) for India; Sarkodie and Samuel (2018) for South-Africa based on ARDL and OLS estimations during 1971-2017, while Bolük and Mert (2014) and Chen *et al.* (2019) found no R-EKC for EU countries based on a P-OLS analysis during 1990-2008, respectively based on ARDL and VECM techniques applied for China during 1980-2014.

Zhang *et al.* (2020) demonstrated for Asian developing economies that renewable energy sources could not only support the EKC hypothesis, but they also enhance the trajectory rate of EKC as well. China and India were found to display the higher efficiency index as a result of their large investments in the renewable energy area. These findings are supported by other studies (Baloch *et al.*, 2020) that studied BRICS countries and showed that Brazil and Russia display the best environmental index and the highest energy efficiency index.

There are studies that investigated the renewable energy-CO2 emissions link even for G7 and/or BRICS countries, but their results also vary a lot. A negative relation between renewable energy consumption and CO2 emissions was found by Maneejuk *et al.* (2020) that investigated and validated EKC hypothesis for EU, G7 or OECD countries, while for other group of countries the EKC was not validated. The highest impact of renewable energy consumption on the environment pollution was found in EU. Zhou *et al.* (2019) also investigated the EKC hypothesis in G7 and BRICS countries and found an inverted U-shaped EKC is validated in G7 countries, based on quantile regression analysis during 1992-2014. For BRICS countries the EKC hypothesis was not validated. Same results for BRICS were achieved by Sinha *et al*. (2019) that found a N-shaped EKC for BRICS during 1990-2017. Chang (2015) didn’t validate the EKC hypothesis for G7 and BRICS countries and found a U-shaped EKC considering emission intensity and carbonization value. This shape was more significant in Germany, Italy and South-Africa. In another study, Chang *et al.* (2018) found a N-shaped EKC for all 12 G7 and BRICS countries. Rahman *et al.* (2019) validated EKC hypothesis based on a PMG analysis for BRICS countries, but also for USA and Canada.

The inverted-N pattern was previously identified for Slovakia and Poland, countries also included in our sample, by Lazăr *et al.* (2019) in case of CO2 emissions and GDP. The study of Simionescu (2021) confirms the U-shaped EKC hypothesis for V4 countries, Bulgaria and Romania. Yao *et al.* (2019) found the same results for developed and developing countries. In Poland, the renewable energy consumption reduces pollution only on short run, but more efforts are necessary to get a long-run sustainable effect.

International trade is considered an important factor of energy demand (Gozgor, 2017). Some studies found a positive relation between trade and greenhouse gas and CO2 emissions. Recent research has shown that product diversification will increase CO2 emissions by increasing the trade volume (Hu *et al.*, 2020).

Al-Mulali *et al.* (2015) stated that trade volume has a positive impact on renewable energy production in Europe. Murshed (2018) found a positive effect of the trade openness on the renewable energy consumption in some selected South Asian countries. Rasoulinezhad and Saboori (2018) found a bidirectional causal relationship between composite trade intensity and renewable energy in a Commonwealth of Independent States.

In a recent study, Zeren and Akkus (2020) demonstrated that the renewable energy is an important factor in decreasing the trade openness for top emerging countries. Alam and Murad (2020) found that the trade openness drives the renewable energy consumption in OECD countries and decreases CO2 emissions. On the other side, Uzar (2020) found that trade openness does not affect the renewable energy consumption in 43 selected countries. Polat (2018) also demonstrated a positive impact of GDP and trade openness on the renewable energy consumption in the developed countries, but he found no effect in the developing countries.

Doytch and Narayan (2016) found that FDI supports the renewable energy consumption, but this effect is more significant in the middle-income countries against low-income countries. Other studies found a positive relation between FDI and non-renewable energy consumption in less-developed countries (Mohammad bin Mohamed, 2016) and many others failed to find any robust evidence (Lee, 2013; Chang, 2015; Zeeb *et al*., 2015). Ali *et al*. (2020) and Rahman *et al.* (2020) observed a positive impact of FDI on pollution. Also, Balsalobre-Lorente *et al.* (2022) indicated a positive effect of FDI on CO2 emission in PIIGS countries from 1990 to 2019 using the DOLS method. So, there are mixed results for the relation between FDI, trade openness, renewable energy consumption, GDP and CO2 emissions and that supports the research gap which needs further investigation, especially for a European developing country such as Romania.

3. Methodology

We used annual data from World Bank Database and Eurostat during 1990-2019.

Table 1. Data Description

Variables	Description	Source
LNCO2	Logarithm CO_2/per capita	World Bank
LNGDP	Logarithm GDP per capita (constant 2010)	World Bank
$LNGDP^2$	Logarithm Square of GDP per capita (Constant 2010)	-
LNTEC	Logarithm Total Energy Consumption	Eurostat
LNREN	Logarithm Renewable Energy Consumption (% total)	World Bank
LNFDI	Logarithm Foreign Direct Investment	World Bank
LNTOP	Logarithm Trade Openness (% GDP)	World Bank

Source: Elaborated by authors

In this study, the Auto Regressive Distributed Model (ARDL) model was used to assess the short-run and long-run relationship between CO2 Emission/capita as a dependent variable and exogenous variables included GDP/capita, the square of GDP/capita, Total Energy Consumption, Renewable Energy Consumption, Foreign Direct Investment, and Trade openness.

The equation in the logarithmic state is as follows:

$$lnCO_2 = \alpha + \beta_1 lnGDP + \beta_2 lnGDP^2 + \beta_3 lnTEC + \beta_4 lnREN + \beta_5 lnFDI + \beta_6 lnTOP + \varepsilon_t \quad (1)$$

The Autoregressive distributed lag (ARDL) model was developed and estimated by Pesaran and Shin (1995), Pesaran *et al.* (1997), and Pesaran *et al.* (2000). The ARDL approach is efficient in cases of small sample size (Pesaran *et al.*, 2001), and potentially eliminates the problems of bias and autocorrelation. In addition, the technique generally provides unbiased estimates of the long-run model and valid t-statistics, even in the presence of the problem of endogeneity (Harris and Sollis, 2003; Salahuddin *et al.*, 2018). The variables in the ARDL model may be I(0), I(1), or a mix of the two. Also, in this model, it is possible to enter variables with different lags in the model, while in traditional models this is not possible (Koondhar *et al.*, 2021). In this study, the following ARDL approach is established to investigate the co-integration relationship:

$$\Delta lnCO2 = \alpha_0 + \sum_{j=1}^{n} b_j \Delta lnCO2_{t-j} + \sum_{j=0}^{n} d_j \Delta lnGDP_{t-j} + \sum_{j=0}^{n} e_j \Delta lnGDP^2{}_{t-j} + \sum_{j=0}^{n} f_j \Delta lnTEC_{t-j} + \sum_{j=0}^{n} g_j \Delta lnREN_{t-j} + \sum_{j=0}^{n} h_j \Delta lnFDI_{t-j} + \sum_{j=0}^{n} k_j \Delta lnTOP_{t-j} + \delta_1 lnCO2_{t-1} + \delta_2 lnGDP_{t-1} + \delta_3 lnGDP^2{}_{t-1} + \delta_4 lnTEC_{t-1} + \delta_5 lnREN_{t-1} + \delta_6 lnFDI_{t-1} + \delta_7 lnTOP_{t-1} \quad (2)$$

b_j, c_j, d_j, e_j, f_j, g_j, h_j, k_j, are short-term estimation coefficients and δ_1, δ_2, δ_3, δ_4, δ_5, δ_6, δ_7, are long-term estimation coefficients in ARDL method and *ln* implies the logarithmic form.

The status of stationary or non-stationary behaviour of a time series can be determined using unit root tests. Augmented Dickey-Fuller (ADF) test is a popular unit root test is proposed by Dickey and Fuller (1979). The null hypothesis of the ADF test is based on the assumption that the variable is non-stationary while the series is stationary in the alternative hypothesis. A variable is non-stationary if the T-statistic is greater than the critical values associated with the test (Khan and Kahn, 2020).

In this paper, the long-run relationship between variables is tested by the Johansen co-integration test (1988) and Johansen and Juselius (1990). This test provides us the determination of the number of co-integration relationships. The null hypothesis in this test is there is no co-integration between variables. The results of Johansen co-integration analysis, based on two tests included trace statistic (indicated by λ trace) and maximum eigen-value statistic (λ max value) along with 95% critical values are provided in ***Table 4***. If the T-statistic of the test is greater than the critical values associated, the null hypothesis is rejected (Khan and Kahn, 2020).

4. Results and discussion

According to the results indicated in ***Table 2***, the variables included that LNCO2, LNGDP, LNGDP2, LNTEC, and LNREN are non-stationary at the level, but in the first difference state, the variables are stationary, so the series are I(1). Also the LNFDI and LNTOP are stationary in level state, so it's I(0).

Table 2. The Results of Unit Root Test

Variable	Description	ADF Test		Outcome
		Statistic in level	First Differences	
$LNCO_2$	CO_2 Emission per capita	-3.46	-3.99	I_1
LNGDP	Per capita Gross Domestic	-2.63	-3.75	I_1
$LNGDP^2$	square of GDP	-2.57	-3.74	I_1
LNTOP	Trade openness	-3.8	-	I_0
LNTEC	Total Energy Consumption	-3.21	-4.5	I_1
LNREN	Renewable Energy Consumption	-2.05	-4.49	I_1
LNFDI	Foreign Direct Investment	-10.5	-	I_0

Source: Authors' estimations

The critical values at the significance level of 1, 5 and 10% are -4.32, -3.58 and -3.22, respectively.

The correlation matrix results indicated in ***Table 3*** revealed that a negative correlation exists between LNCO2 emission with LNGDP, $LNGDP^2$, LNFDI inflows, LNTOP and LNREN, while a positive correlation between LNCO2 emission with LNTEC.

Table 3. Results of Correlation Matrix

Correlation t-Statistic Probability	$LNCO_2$	LNGDP	$LNGDP^2$	LNTOP	LNTEC	LNREN	LNFDI
$LNCO_2$	1.000						

LNGDP	-0.648	1.000					
	-4.424	---					
	0.00	---					
$LNGDP^2$	-0.648	0.999	1.000				
	-4.43	416.00	---				
	0.00	0.00	---				
LNTOP	-0.71	0.82	0.82	1.000			
	-5.2	7.52	7.59	---			
	0.00	0.00	0.00	---			
LNTEC	0.986	-0.717	-0.717	-0.75	1.000		
	31.3	-5.347	-5.35	-5.94	---		
	0.00	0.00	0.00	0.00	---		
LNREN	-0.906	0.73	0.73	0.74	-0.9	1.000	
	-11.13	5.6	5.58	5.83	-10.75	---	
	0.00	0.00	0.00	0.00	0.00	---	
LNFDI	-0.782	0.54	0.53	0.59	-0.794	0.87	1.000
	-6.52	3.33	3.32	3.88	-6.8	9.23	---
	0.00	0.00	0.00	0.00	0.00	0.00	---

Source: Authors' estimations

The results in ***Table 4*** indicate that, in all states, the T-statistic of the test is greater than the critical value, so there is co-integration between variables. Both the maximum eigenvalue and the trace statistics indicate that there is at least (3) co-integration vector.

Table 4. The Results of Johansen Co-integration Test

Null Hypothesis	Alternative Hypothesis	Eigenvalue	λ_{Trace} Value	Critical Value	Probability
λ_{Trace} Test					
r=0	r>0	0.94	256.2	125.6	0.00
r≤1	r>1	0.88	176.3	95.75	0.00
r≤2	r>2	0.82	117.69	69.81	0.00
r≤3	r>3	0.75	70.8	47.85	0.00
λ_{Max} Test		Eigenvalue	λ_{Max} Value		
r=0	r>0	0.94	79.8	46.2	0.00
r≤1	r>1	0.88	58.7	40.07	0.00
r≤2	r>2	0.82	46.8	33.8	0.00
r≤3	r>3	0.75	37.5	27.5	0.00

Source: Authors' estimations

Table 5 and ***6*** present the results of short-run and long-run estimations of the ARDL model. According to our results, GDP per capita is negatively associated with the CO2 per capita emissions, while squared GDP/capita is positively associated with the CO2/capita emissions. That illustrates a U-shaped EKC in Romania between economic growth and environmental degradation. In the early stage of economic progress, this supports the improvement of environment, but after a while, the robust economic growth contributed to the environment degradation in Romania. Same results were achieved both in the short-run and in the long-run. These findings were validated by the results of Chang (2015) for G7 and BRICS countries and by Simionescu (2021) for Visegrad countries, Romania and Bulgaria. In the short-run, total energy consumption and renewable energy consumption decrease pollution, but in the long-run, total energy consumption determines a rise of CO2 emissions. Renewable energy consumption remains negatively associated to the CO2/capita emissions, which is in line with the previous findings (Apergis and Payne, 2012; Tugcu *et al.*, 2012; Yao *et al.*, 2019; Allard *et al.*, 2018; Erdogan *et al.*, 2020; Jahanger *et al.*, 2022a). Trade openness is negatively associated with CO2/capita emissions, which means that globalization process and the strength of trade relations between countries contributed to the environmental improvement in the long-run. Same results were achieved by Alam and Murat (2020), Polat (2018) for developed economies. Also, Jahanger *et al.* (2022b) revealed that globalization boosts the environmental quality (ecological footprint) in 73 developing countries. FDI is negatively associated with CO2/capita emissions in the short-run, but positively correlated with CO2/capita emissions in the long-run. This result is in line with the research Balsalobre - Lorente *et al.* (2022). This change of the sign in the relation between FDI and CO2/capita emissions show that FDI inflows should be directed to the economic sectors that are low-intensive in the use of fossil fuel energy, which it was not the case of Romania during the analysed period. These results are in line with the findings of Ali *et al.* (2020) and Rahman *et al.* (2020) that observed a positive impact of FDI on pollution, or with the results achieved by Mohammad bin Mohamed (2016) who found a positive relation between FDI and fossil fuel energy consumption in less developed countries.

Most of the coefficients estimated by the ARDL model are determined at 1% significance level.

Table 5. Results of Short-run ARDL Model

Variable	Coefficient	Std-Error	T-Statistic	Probability
LNCO2(-1)	0.12*	0.06	1.9	0.07
LNCO2(-2)	-0.13**	0.04	-3.2	0.00
LNGDP	-0.53***	0.05	-9.1	0.00
$LNGDP^2$	0.03***	0.004	8.05	0.00
LNTOP	0.04***	0.02	1.8	0.08
LNTOP(-1)	-0.06***	0.02	-2.68	0.01
LNTEC	-1.00***	0.06	15.2	0.00
LNREN	-0.1***	0.01	-5.5	0.00
LNFDI	-0.01**	0.004	2.7	0.01
ECM(-1)	-0.76***	0.2	-3.7	0.00

Source: Authors' estimations

Table 6. Results of Long-run ARDL Model

Variable	Coefficient	Std-Error	T-Statistic	Probability
LNGDP	-0.52***	0.04	-11.4	0.00
$LNGDP^2$	0.03***	0.003	9.9	0.00
LTOP	-0.01*	0.03	-0.49	0.62
LNTEC	0.98***	0.03	28.6	0.00
LREN	-0.09***	0.01	-5.6	0.00
LNFDI	0.01**	0.004	2.63	0.01

*Note: ***, **, * at the significance level of 1, 5 and 10%.*

Source: Authors' estimations

Table 7 presents the results of the diagnosis test (Breusch-Godfrey LM test, Breusch-Pagan-Godfrey test and Ramsey test) that indicate no serial error correlation.

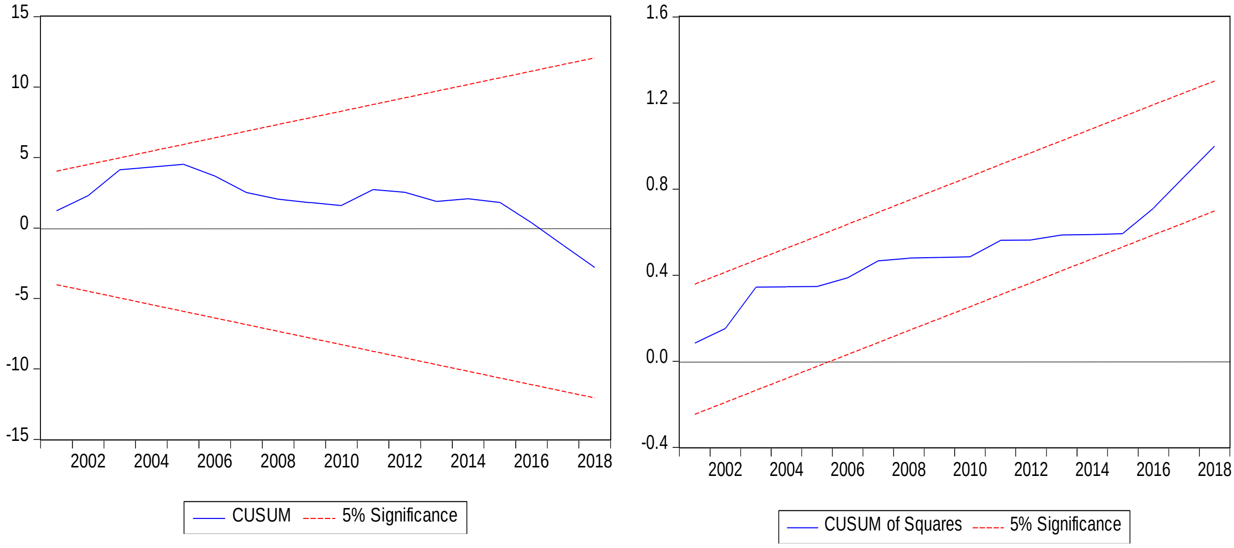
Table 7. Diagnostic Test

Test	F-Statistic	Probability	Outcome
Breusch-Godfrey serial correlation LM test	0.2	0.81	No serial correlations
Breusch-Pagan-Godfrey heteroscedasticity test	0.62	0.75	No heteroscedasticity
Ramsey test	0.21	0.83	Correct Functional form

Source: Authors' estimations

To ensure the robustness of our results we employ structural stability tests on the parameters of the long-run results based on the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests as suggested by Pesaran *et al*. (1997). The plots of the CUSUM and its squares at the 5% level of significance are illustrated in ***Figure 1***. Both the plots indicate that the plotlines for both tests are within the critical limits, endorsing the accuracy of the long-run estimates.

Figure 1. Cusum and Cusumsq



Source: Authors' estimations

The following step is the VECM analysis, which is used to find out the relationship between these variables and the direction of causality. We can notice more short-run causalities between the analysed variables.

There is a bidirectional causality from GDP and GDP^2 to renewable energy consumption share.

A positive uni-directional causality was found form GDP, GDP^2, trade openness and renewable energy consumption to total energy consumption.

Same positive uni-directional causality can be observed from CO_2 and renewable energy to FDI.

A positive uni-directional causality can be observed from FDI to trade openness, and from trade openness to renewable energy consumption.

Table 8. VECM causality

	Wald χ^2 Statistics							Long-term t-statistic
Variables	LNCO2	LNGDP	$LNGDP^2$	LNTOP	LNTEC	LNREN	LNFDI	ECM (-1)
LNCO2	---	1.95 (0.16)	1.92 (0.16)	0.3 (0.58)	0.2 (0.64)	0.75 (0.38)	2.79* (0.09)	-1.51* (-0.07)
LNGDP	1.6 (0.2)	---	1.03 (0.3)	1.07 (0.29)	3.68* (0.05)	2.96* (0.08)	0.02 (0.88)	0.64 (0.20)
$LNGDP^2$	1.5 (0.21)	1.31 (0.25)	---	1.14 (0.28)	3.58** (0.02)	2.91* (0.08)	0.04 (0.83)	11.01 (0.22)
LNTOP	1.4 (0.23)	0.03 (0.85)	0.03 (0.86)	---	2.77* (0.09)	3.36* (0.06)	0.99 (0.31)	-2.38** (0.03)
LNTEC	0.05 (0.8)	2.55 (0.11)	2.56 (0.1)	0.003 (0.95)	---	0.75 (0.38)	0.56 (0.45)	-0.07 (0.91)
LNREN	2.6 (0.1)	6.98*** (0.00)	6.8*** (0.00)	0.93 (0.33)	3.17* (0.07)	---	8.56*** (0.00)	2.48* (0.09)
LNFDI	0.58 (0.44)	0.72 (0.39)	0.77 (0.38)	13.73*** (0.00)	0.53 (0.46)	0.66 (0.41)	---	2.98 (0.66)

*Note: ***, **, * at the significance level of 1, 5 and 10%.*

Source: Authors' estimations

5. Conclusions and policy recommendations

In this study, we aimed to investigate the existence of Environmental Kuznets Curve in Romania and its shape during 1990-2019, based on an ARDL model with short-run and long-run estimations, considering total energy consumption, renewable energy consumption, FDI and trade openness. Findings suggest a U-shaped curve, a positive linkage between total energy consumption or FDI and CO2 emissions/capita in the long-run, a negative relation between renewable energy share of total energy mix and emissions, and a negative relation between trade openness and CO2 emissions/capita. We have investigated the co-integration of the selected variables and we have found there is a long-term relationship between them. We have applied diagnosis tests to prove the lack of serial errors correlation and Cusum/Cusumsq to prove the robustness of our results based on the ARDL model. We also investigated the short-run and long-run causality between the analysed variables using VECM causality and we found that a bidirectional causality from GDP and GDP2 to renewable energy consumption share. A positive uni-directional causality was found from GDP, GDP2, trade openness and renewable energy consumption to total energy consumption. Same positive uni-directional causality can be observed from CO2 and renewable energy to FDI. A positive uni-directional causality can be observed from FDI to trade openness, and from trade openness to renewable energy consumption.

Based on our results, during the first stages of economic development, we can notice a decrease of CO2 emissions, but during the advanced stages of the economic development we could notice an environmental degradation. So, Romania should pay great attention to the environmental issues in the future; therefore, it should increase its trade openness and the share of the renewable energy share in the total energy consumption to properly address these issues. The FDI inflows should be mainly directed to the export-oriented sectors in order to increase the trade openness and to the less intensive fossil fuel energy sectors. In this regard, these types of foreign investors attracted in these specific economic sectors should benefit of some significant fiscal or non-fiscal facilities. The national authorities should also support the development of the renewable energy sources by allocating public funds for the research and development in this sector, in a close partnership with the private companies interested to invest in clean technologies and clean energy sources.

The current study faces some limitations such as a lack of access to the data of some variables for the years before 1990. Also, some variables affecting the environmental quality were removed from the model due to incompatibility with the estimated model. This paper allows some directions for further research, by adding new control variables into the model, such as economic complexity index, economic uncertainty index, financial development index or investigating the impact of all these exogenous variables on the ecological footprint in Romania, because CO2 emissions represent only a side of the overall impact of the economic activity on the environment and a more comprehensive indicator for measuring this overall impact is ecological footprint, very used in the last years studies on the environmental topics.

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