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RENEWABLE ENERGY, ENVIRONMENT AND GDP IN HIGH-INCOME COUNTRIES: EVIDENCE FROM EUROPE

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Abstract. The research paper considers the dual role of renewable energy in achieving environmental safety and promoting economic growth. The ARDL methodology was applied to data collected from high-income countries in Europe in the period 1990–2020.The results showed that there was a positive and strong effect of renewable energy on reducing CO_2 emissions in the long term, but its effect in the short term was weak. Fossil energy and economic growth positively affected the increase in emissions. Likewise, the expected role of renewable energy in promoting economic growth was partially achieved in the short term, but was not achieved in the long term. The study encouraged the efforts of European countries to promote and accelerate the transition towards renewable energy in order to promote environmental safety and achieve energy independence from abroad.

Keywords: *Autoregressive distributed lag (ARDL), Europe, CO_2 emissions, economic growth, high-income countries, renewable energies.*

JEL Classification: Q43, O55, C22

INTRODUCTION

The challenges facing the world have increased, as a result of the continued emission of polluting gases from the petroleum and extractive industries, and the consumption of fossil energy. These gases, especially CO_2, are directly responsible for causing widespread damage, such as the exacerbation of global warming, the deterioration of environmental safety, and the decline of biological diversity (Hormio, 2023; Al-Mulali et al., 2015; Zandalinas et al., 2021; Acheampong & Opoku, 2023; Zhang et al., 2023; Eregha et al., 2022; Butt et al., 2023). The goal is to lead to global climate neutrality by 2050, through implementing the provisions of the European Green Deal(2019). European countries are making strenuous efforts to solve the chronic link between economic growth and sources of pollution, a link imposed by the industrial revolution and continued in response to the requirements of growth and economic development, resulting in the emission of more than 34 million kilotons of CO_2 gas yearly, in which the Group of Eight contributes by 85 %, and the European Union by 29 % (Hickel, 2020).

The European Green Deal is considered a strong ground upon which the European Union rests in order to accelerate the transition towards clean renewable energy, and the abandonment of polluting fossil energy. It is an integrated document that deals with all the details of the transformation process according to a specific timetable.

The most important details that the EGD document focused on for the transition towards renewable energy are as follows: It looks at the sources and mechanisms of financing (AURESII, 2020); Energy efficiency methods and techniques (Kolosok et al., 2021); Sectors with priority to be targeted; Harnessing digitization and artificial intelligence systems in facilitating implementation, evaluation and monitoring procedures (Hu et al., 2022); (Hu, Wu, Anvari-Moghaddam & Zhao, 2022); Establishing a new energy infrastructure that meets the standards and requirements of renewable energy (OECD, 2013); Promoting the circular economy by intensifying recycling of wastes; Work to stop the erosion of biodiversity; Mobilizing and ensuring the flow of necessary investments, which was estimated according to European Commission at about 260 billion Euros annually until 2030; Intensifying research and innovation efforts to reach new technologies that guarantee sustainable solutions.

The motive of European countries towards renewable energies, in addition to the urgent environmental requirements, is also an attempt to gain independence from energy dependence on abroad, considering energy as a vital strategic commodity (InstitutMontaigne, 2021). Most European countries lack fossil energy sources necessary for their economic and social uses, as they resort to importing them from abroad, and thus they are vulnerable either to unfavorable price fluctuations, or shortages of supplies due to security disturbances and conflicts, whether in exporting countries, or at the international level such as the Russian invasion of Ukraine, or even due to natural disasters or health crises such as the Covid-19 crisis.

The efforts of European countries have resulted in the transition to a situation of relative energy mix, traditional-renewable, but there is still a long way to go for renewable energy sources. Their percentage of the total energy consumed in the European Union is changing at an increasing rate with time, reaching about 17.82 % in 2015 of the total energy mix, and 21.77 % in 2021, according to Eurostat data(Eurostat, 2023).

European countries – since most of them are high-income according to the classification of the World Bank – are supposed to have the ability to face the obstacles of the energy transition project, especially in the part related to the huge financing aspect required by the process. Funding sources include national budgets, European Union budget, some special funds, as well as tax revenues created in favor of the green economy.

This means that part of the income will be spent on various economic and social energy aspects, which makes us assume that the costs exceed the returns in the short term, in a transitional phase to benefit from greater returns than the costs in the long term on the one hand, and achieve the goal of preserving the environment, by reducing CO_2 emissions least in the medium term on the other hand.

This is what the research problem will investigate, which is unique from the rest of the research by considering the dual impact of renewable energy sources in promoting economic growth and preserving the environment in high-income countries. Focusing on high-income countries gives a new analytical angle, based on the idea that these countries have financial and technological capabilities that qualify them to shift towards renewable energy, while maintaining acceptable global economic growth rates, and thus is the most hopeful for achieving real and effective results in confronting climate change.

The structure of the research is as follows: the first section contains the literature review, the second section deals with data and methodology, the third section presents the results, the fourth section discusses the results and the last one concludes the research.

1. LITERATURE REVIEW

Interest in climate change has emerged since the 1970s in the work of Callendar (1938) through his study of the impact of carbon dioxide emissions from industrial activities on the warming of the atmosphere in the United States. After that, interest evolved from the academic and scientific circles to political awareness, and this was translated into international agreements and treaties, under the auspices of the United Nations, perhaps the most important of which are the Kyoto Protocol (UN, 1998) and the Paris Climate Agreement (UN, 2015).

These agreements tried to draw features of confronting the problem of climate change, and the associated complications. Climate change is affected by greenhouse gas emissions, mainly CO_2, and emissions mainly come from fossil energy necessary for economic growth and social requirements. Efforts are united towards replacing fossil energy with clean renewable energy sources as a permanent solution whenever possible. The concerned authorities accompanied this endeavor by drawing up scenarios that expect the energy transition to take place, and achieving zero CO_2 emission by 2050 (IEA, 2021; 2023), and this remains dependent on the ability of renewable energy technology to compensate for fossil energy in terms of quantity, and to compete with it in terms of costs.

At the applied level, several studies have focused on the network of relationships among economic growth, climate change, and energy. Below we review examples of them.

If we start with the work of Gricar et al. (2022), theystudied the impact of GDP, among a group of other variables, on greenhouse gas emissions. The study included a comparison between the EU-27 and Norway and Iceland, over a period extending between 2010–2021. VAR methodology was used. The results showed a positive and significant impact of GDP on greenhouse gas emissions in the EU-27 countries.

Alola et al. (2019) dealt with the issue of the impact of trade policies, economic growth, fertility rate and energy on the ecological footprint in Europe. They used ARDL analysis on data covering the period 1997–2014, they confirmed that fossil energy was opposite to renewable energy in terms of impact on the environment. They recommended the European Union to strengthen its obligations related to achieving emissions targets in order to meet the requirements of sustainable development in this item.

Armeanu et al. (2017) studied the relationship between renewable energy sources and the economic growth of the EU-28 group between 2003 and 2014. They found that the share of renewable energy in the total energy consumed did not meet the ratios set by the Union's policies, and they concluded that all types of renewable energy had a positive impact on per capita rates of output, especially biomass energy. The same result was proven by the study of Soava et al. (2018), which was conducted on the same spatial scale with a different time scale that included the period 1995–2015. They recommended strengthening and encouraging the European Union's efforts to shift towards renewable energy.

Madaleno and Nogueira (2023) mainly studied the impact of CO_2 emissions and renewable energy sources on economic growth, and employed several determinants for that. Their study included the group of EU-27 countries between 1994 and 2019. They concluded that several determinants had a positive impact on economic growth driven by the large consumption of fossil energy, and thus an increase in growth at the expense of an increase in CO_2 emissions, which negatively affected environmental safety.

Kukharets et al. (2023) studied the issue of energy security in the European Union, by examining the impact of the level of renewable energy, as well as the level of development, on the degrees of dependence on energy imports, within the framework of the European Green Deal. It was done using regression analysis of data covering the period 2011–2021. The results found that when renewable energy reached 32 % of the total energy consumed in a country, the development of it stopped increasing dependence on imported energy. The results also added to the need for the shares of renewable energy in each EU country to be consistent with the levels of its per capita GDP, and showed that energy security and independence were achieved when the share of renewable energy reached 40 % of the total energy consumed in a country.

Mirziyoyeva and Salahodjaev (2023) investigated the impact of renewable energy and GDP on CO_2 emissions in highly globalized countries. The study covered the period 2000–2019. A two-step GMM estimator was used on panel data for 50 countries. The results showed that renewable energy and globalization led to a reduction in CO_2 emissions, as well as the existence of a threshold of per capita GDP amounting to 67 200 international dollars, at which a shift occurred to reduce CO_2 emissions instead of increasing them, according to the U-shaped relationship that linked per capita GDP with CO_2 emissions.

Deka et al.(2023) studied the impact of GDP and energy on carbon emissions. They used the GMM estimator on panel data covering the period 1990–2019 for EU-27 countries. The research results concluded that renewable energy reduced CO_2 emissions, in contrast to GDP and fossil energy, which exacerbated CO_2 emissions and thus harmed the environment.

Based on previous literature, the most important hypotheses are as follows:

High-income countries can switch from using fossil energy to clean energy by the availability of the necessary requirements such as money and efficient human resources. Renewable energy is supposed to contribute to enhancing economic growth and reducing the level of CO_2 emissions in high-income countries.

Also, it is assumed that levels of economic growth, which depend more on fossil energy, will have the effect of further exacerbating CO_2 emissions in these countries.

Continuing to consume more traditional energy contributes to increasing CO_2 emissions, on the one hand, and enhances economic growth as it is one of the most important inputs to production and service processes, on the other hand.

2. METHODOLOGY

2.1. Data

The sample of study was taken from the group of European countries according to the availability of data covering the period between 1990 and 2020. Table 1 contains 33 countries distributed according to the World Bank's classification of countries based on income. We have 27 high-income countries, 5 upper-middle-income countries, and only one lower-middle-income country.

Table 1. Classification of Sample Countries according to Income Level

High income			Upper middle income	Lower middle income
Austria	Greece	Poland	Belarus	Ukraine
Belgium	Hungary	Portugal	Bulgaria	
Cyprus	Iceland	Romania	North Macedonia	
Czech	Ireland	Slovakia	Russia	
Denmark	Italy	Slovenia	Turkey	
Estonia	Latvia	Spain		
Finland	Luxembourg	Sweden		
France	Netherlands	Switzerland		
Germany	Norway	United Kingdom		

Source: Made by the author based on the WorldBank (2022)

To determine the impact of renewable energy on reducing environmental degradation, the first panel ARDL model was estimated, using variables taken in logarithm from the World Development Indicators issued by the World Bank, except the energy consumption variable, which was taken from our world in data website (OWD). The dependent variable in this model is the logarithm of dioxide carbon emissions.

The second model shows the impact of renewable energy on the development of economic growth rates represented by GDP per capita as a dependent variable, and the rest of the variables are independent. They are also taken in logarithm from the World Development Indicators, except the energy consumption variable, which was taken from OWD.

The per capita values of independent variables are calculated by dividing the variable of a country by its population.

Table 2 summarizes the variables used, their measurements and sources.

Table 2. Description of Variables

Notation	Variable	Measurement	Source
First model			
LCO_2	Log of dioxide carbon emissions	Kilotons	WDI
LEC	Log of Energy consumption	Terawatt-hour	OWD
LGDP	Log of GDP	constant 2015 US$	WDI
LRE	Log of renewable energy	% of total energy consumption	WDI
Second model			
LGDPC	Log of GDP per capita	constant 2015 US$	WDI
LEC	Log of Energy consumption per capita	Terawatt-hour	OWD
LKLRC	log of capital labor ratio per capita	constant 2015 US$	WDI
LLC	Log of labor per capita	Number	WDI
LREC	Log of renewable energy per capita	% of total energy consumption	WDI

Source: Made by the author

2.2. Empirical Methods

In the first step, we study the stationarity of the time series, by examining the unit root, using various well-known tests. We then estimate two models. The first identifies the impact of both renewable energy and economic growth on climate change; the second determines the impact of renewable energy on economic growth. In both models, we add some control variables. In both, we use the panel autoregressive distributed lag model (ARDL) as proposed by Pesaran & Shin (2012) and Pesaran et al. (2001).

Using the ARDL Panel approach allows studying the relationship between variables, and determining the effect of the independent ones on the dependent ones. What distinguishes this approach is that it accepts that the model contains variables with different degrees of integration, so they are either stationary at the level, stationary at the first difference, or a combination of both.

It also allows studying the relationships between variables in the short run and in the long run at the same time. After revealing the existence of a cointegration relationship, the long-run relationship coefficients are estimated and the error correction model is estimated, which includes the short-run coefficients and the speed of adjustment coefficient necessary to return to equilibrium.

In addition to the current values, this approach also allows the lags to contribute to explaining the values of the dependent variable, by having the lags appear as independent variables in the model, and representing the effect of the previous values of the dependent variable and the independent variables on the current values of the dependent variable. The lag length is determined using one of the statistical criteria AIC or SC.

The ARDL model is denoted as follows: ARDL (p, q_1, q_2…), where p denotes the lag length of the dependent variable, and q_1, q_2… denote the lag lengths of the independent variables.

The first model is shown as follows:

$$LCO2_{it} = \phi_i \left(LCO2_{i,t-1} - \gamma_{1i} LEC_{i,t} - \gamma_{2i} LGDP_{i,t} - \gamma_{3i} LRE_{i,t} \right) + \sum_{j=1}^{p-1} \delta_{ij} \Delta CO2_{i,t-j} + \sum_{j=0}^{q-1} \beta_{1i} \Delta LEC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2i} \Delta LGDP_{i,t-j} + \sum_{j=0}^{q-1} \beta_{3i} \Delta LRE_{i,t-j} + \mu_i + \varepsilon_{it} \quad (1)$$

γ – the long-run coefficients;
δ and β – the short-run coefficients;
ϕ – the speed of adjustment to the long-run equilibrium;
ε_{it} – the error term;
i and t – the country and period, respectively.

The second model is represented as follows:

$$LGDPC_{it} = \phi_i \begin{pmatrix} LGDPC_{i,t-1} - \gamma_{1i} LECC_{i,t} - \gamma_{2i} LKLRC_{i,t} \\ -\gamma_{3i} LLC_{i,t} - \gamma_{4i} LREC_{i,t} \end{pmatrix} + \sum_{j=1}^{p-1} \delta_{ij} \Delta LGDPC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{1i} \Delta LECC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2i} \Delta LKLRC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{3i} \Delta LLC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{4i} \Delta LREC_{i,t-j} + \mu_i + \varepsilon_{it} \quad (2)$$

3. EMPIRICAL RESULTS

First of all, we look at the first model that determines the impact of renewable energy on reducing environmental degradation by reducing CO_2 emissions in the sample countries, and then follow the second model that determines the impact of renewable energy on the development of economic growth rates.

3.1. The First Model

Unit root test: we will start by studying the stationarity of variables by conducting the necessary unit root tests on them. The results are shown in Table 3.

Unit root tests were conducted on all variables. Table 3 summarizes the results, and it appears on the left side that some variables are stationary at the level according to some tests, and non-stationary according to other tests at different significance levels, which necessitated re-tests on all variables at the first differences. The results are summarized in the right part of Table 3, and it was found that all variables are stationary at the significance level of 1 % according to the four tests used. This means that all variables are integrated of order one I(1), which allows us to use the panel ARDL methodology.

Table 3. Unit Root Test

	At Level				At First difference		
Variables	Intercept and trend	Intercept	None		Intercept and trend	Intercept	None
Levin, Lin, and Chu							
LCO_2	−2.80*	−3.54*	−5.10*		−20.0*	−22.8*	−25.1*
LEC	−1.82**	−3.66*	−2.43*		−17.9*	−19.5*	−25.8*
LGDP	−3.40*	−4.53*	18.5		−10.9*	−13.4*	−13.7*
LRE	−2.47*	−1.75**	5.45		−17.1*	−20.2*	−20.2*
Im, Pesaran and Shin							
LCO_2	−1.11	−0.99	/		−22.6*	-24.0*	/
LEC	−1.51	−3.27*	/		−23.1*	-21.9*	/
LGDP	−3.48*	1.38	/		−12.5*	-15.7*	/
LRE	−1.88**	2.06	/		−19.3*	-22.2*	/
ADF—Fisher Chi-square							
LCO_2	95.9*	114*	125*		516*	561*	684*
LEC	88.0**	120*	88.3**		510*	520*	702*
LGDP	130*	89.8**	4.28		284*	356*	363*
LRE	99.8*	95.3**	21.8		442*	524*	574*

* Significant at 1 %, ** significant at 5 %
Source: Author's compilation from E-Views outputs

Estimation results of the first model: The first model was estimated to find out the impact of renewable energy and economic growth on CO_2 emissions. The results are summarized in Table 4.

Table 4. Estimation Results

Variables	**Δ LCO_2**	**t-stat**	**Prob.**
	LONG-RUN		
Δ LEC	0.873227***	(60.40)	0.0000
Δ LGDP	0.026686***	(3.93)	0.0001
Δ LRE	−0.062147***	(−13.96)	0.0000
ECT(−1)	−0.590842***	(−4.43)	0.0000
	SHORT-RUN		
Δ LEC	0.353966**	(2.45)	0.0148
Δ LGDP	−0.005458	(−0.05)	0.9594
Δ LRE	−0.037112	(−0.52)	0.6026
Δ LRE(−2)	−0.127048*	(−1.74)	0.0816

*** Significant at 1 %, ** significant at 5 %, *significant at 10 %, Δ is the difference operator.
Source: Author's compilation from E-Views outputs

The results show that there is a long-term cointegration relationship between the variables of the model, through the ECT coefficient, which is equal to −0.59. It is a negative and statistically significant value, according to the Student test and the probability value. Its economic significance means that the rate of return to the equilibrium position in the long run amounts to 59 % annually, that is, we need about 20.34 months to fully return to the equilibrium position, which is the time required for the interaction and impact of the independent variables on the dependent variable to rebalancing.

In the long run, we note that all coefficients of independent variables are statistically acceptable. The coefficient of energy consumption equal to 0.87 is acceptable at the significance level of 1 %. Its value means economically that an increase in energy consumption by 1 TW leads to an increase in CO_2 emissions by 0.87 kt.

This result confirms the significant impact caused by energy consumption in high-income countries on environmental degradation through the effect of toxic gases on the various components of the environment such as air, water and soil, on the one hand, and their impact on global warming and climate change, on the other hand.

The GDP variable coefficient is also statistically significant. Its impact on the emission of CO_2 is positive, and it contributes significantly to environmental degradation by 0.03 kt of CO_2 for every $1 of output. Increasing output allows for an increase in the need for unclean energy through two channels, which are the consumption channel and the investment channel.

In contrast to the two previous variables, the coefficient of renewable energy is statistically significant, but it negatively affects the emission of CO_2 gas. Its coefficient is −0.06, which means that an increase in renewable energy consumption by 1 % of the total energy consumed in the sample countries leads to a decrease in CO_2 emissions by 0.06 kilotons, which is a good result and suggests that renewable energy represents the main pillar and future hope for reducing environmental degradation and global warming, and dealing with unclean energies effects.

In the short run, we notice that the energy consumption variable has a positive and significant impact on CO_2 emissions; its coefficient is 0.35, which is statistically acceptable at the significance level of 5 %. It is explained economically that an increase in energy consumption by 1 terawatt leads to an increase in CO_2 emissions by 0.35 kt.

On the other hand, we find that the GDP variable has no effect on CO_2 emissions in the short run, because its coefficient is not statistically acceptable at all levels of significance. Likewise, the variable consumption of renewable energy did not prove its effect on CO_2 emissions, but the coefficient of renewable energy consumption with two lags was statistically acceptable at the significance level of 10 %. It is equal to −0.12, which means that an increase in the consumption of renewable energy by 1 % of the total energy consumed leads to decrease in CO_2 emissions by 0.12 kt.

3.2. The Second Model

Unit root test: We use the same previous tests to detect the unit root in different variables used in the second model. The results are summarized in Table 5.

Table 5. Unit Root Test

	At Level				At First difference		
Variables	Intercept and trend	Intercept	None		Intercept and trend	Intercept	None
Levin, Lin, and Chu							
LGDPC	−6.15*	−3.89*	13.70		−12.95*	−11.28*	−13.57*
LECC	−2.67*	−1.14	4.10		−15.46*	−19.12*	−26.27*
LKLRC	-0.36	−2.87*	−4.07*		−21.95*	−14.16*	−28.67*
LLC	-0.22	−3.44*	−4.83*		−16.79*	−16.36*	−19.13*
LREC	−2.46*	−2.87*	−5.60*		−17.30*	−20.22*	−21.07*
Im, Pesaran and Shin							
LGDPC	−3.56*	2.36	/		−10.89*	−12.21*	/
LECC	−1.81**	−1.10	/		−20.28*	−21.58*	/
LKLRC	−3.33*	−2.05**	/		−16.58*	−17.39*	/
LLC	1.19	0.40	/		−16.54*	−17.07*	/
LREC	−2.00**	1.01	/		−19.46*	−22.31*	/
ADF—Fisher Chi-square							
LGDPC	352.8*	58.88	3.14		253.7*	272.5*	298.3*
LECC	91.30**	108.6*	24.39		445.1*	511.9*	718.7*
LKLRC	101.*	100.2*	102.2*		537.3*	402.5*	815.2*
LLC	65.63	66.96	116.0*		353.9*	398.0*	565.2*
LREC	100.6*	100.3*	222.4*		446.3*	527.5*	606.0*

* Significant at 1 %, ** significant at 5 %
Source: Author’s compilation from E-Views outputs

The results of the unit root tests shown in the left part of the table above, related to conducting tests on the variables at level, show that the variables are stationary according to some tests and non-stationary according to other tests. Therefore, it can be concluded that all variables are non-stationary at level. This prompted the re-testing the variables at first differences. The results are shown in the right part of Table 5. We note that all variables are stationary at the significance level of 1 %, which means that they are integrated of the first order I(1). Thus, it is possible to use the ARDL method.

Estimation results of the second model: After studying the stationarity and making sure that the necessary conditions are met for using the ARDL methodology, we will apply it to the data of the sample countries, to reveal the impact of renewable energies on the development of economic growth rates in the long and short terms. The results are shown in Table 6.

Table 6. Estimation Results

Variables	Δ LGDPC	t-stat	Prob.
	LONG-RUN		
Δ LECC	0.073109***	(5.10)	0.0000
Δ LKLRC	0.195911***	(23.89)	0.0000
Δ LLC	0.688034***	(0.33)	0.0000
Δ LREC	0.003749	(0.40)	0.6865
ECT(−1)	−0.593210***	(−5.85)	0.0000
	SHORT-RUN		
Δ LGDPC(−3)	0.147520***	(3.29)	0.0011
Δ LECC	0.133203***	(3.45)	0.0006
Δ LECC(−1)	0.118830**	(2.26)	0.0242
Δ LECC(−2)	0.088172**	(2.47)	0.0138
Δ LKLRC	0.094863**	(2.50)	0.0126
Δ LLC	−0.002454	(−0.01)	0.9856
Δ LREC	0.058718**	(2.25)	0.0246
CONST	0.009865***	(6.10)	0.0000

*** Significant at 1 %, ** significant at 5 %, *significant at 10 %. Δ is the difference operator.
Source: Author's compilation from E-Views outputs

The error correction coefficient is statistically significant at the level of 1 %, its value is negative and equal to −0.59, indicating the existence of a long-term cointegration relationship between the various variables. It is explained economically that the return to equilibrium takes place by 59 % every year. To return to the total equilibrium, we need about 20.34 months, which is the sufficient time to complete the full effect of the independent variables on the dependent variable until it returns to the equilibrium position.

The results of the estimation of the second model in Table 6 show that the variable per capita energy consumption affects economic growth in the long run, the coefficient is 0.07, it is statistically acceptable at the level of 1 %, and it agrees with the economic theory. It is explained that an increase in per capita energy consumption by 1 terawatt leads to an increase in per capita GDP by $0.07. This proves the significant role of energy in the operations of various economic activities, especially in the sample countries, as most of them are industrialized countries.

The capital-labor ratio is also statistically significant at the level of 1 %, with a positive coefficient equal to 0.19. Increasing it by $1 leads to an increase in per capita GDP by $0.19 in the long run. This is a significant and expected effect, given that capital is one of the most important determinants of economic growth.

Labor productivity per capita is also acceptable from an economic point of view because its coefficient is positive, and it is statistically acceptable at the significance level of 1 %. Increasing it by one worker leads to an increase in GDP per capita by \$ 0.7, which proves the essential role of labor in long-run economic growth, in high-income countries.

In contrast to the previous variables, the renewable energy variable could not prove its impact on economic growth in the long run, due to the non-acceptance of its coefficient statistically at all levels of significance, which is indicated by the probability value of 0.68.

As for the short run, we note from the table that the third lag of GDP per capita affects the current GDP per capita values, its coefficient is 0.14 and it is statistically positive and significant at the level of 1 %. Increasing it by \$1 leads to an increase in GDP per capita by \$0.14.

Likewise, energy consumption per capita affects output per capita, through its current values and also its first and second lags, with coefficients of 0.13, 0.12, and 0.1, respectively, which are positive and statistically significant values at the 5 % level. Increasing each of them by 1 terawatt leads to an increase in GDP per capita by \$0.13, \$0.12 and \$0.1, respectively.

The coefficient of capital-labor ratio is positive and statistically acceptable at the significance level of 5 %. Increasing it by \$1 leads to an increase in GDP per capita by \$0.09 in the short run, in contrast to the share of work per capita, which has no effect on economic growth in the short run, because its coefficient is not statistically acceptable at all levels of significance.

Consumption of renewable energy per capita positively affects economic growth in the short run. An increase in the share of renewable energy per capita by 1 % as a percentage of the total energy consumed leads to an increase in GDP per capita by \$0.06. This value is statistically proven by its acceptance at the significance level of 5 %.

4. DISCUSSION

The results extracted from the first model showed the positive and strong effect of renewable energy on reducing CO_2 emissions in the long term, which was expected, as it was consistent with many results of related studies such as Alola et al. (2019), Mirziyoyeva & Salahodjaev (2023), Deka et al. (2023), Armeanu et al. (2017), and Soava et al. (2018).

Renewable energy affects the reduction of CO_2 emissions through two mechanisms. The first is the process of replacing traditional energy sources with renewable energy, which has a direct impact on reducing the volume of current actual emissions to lower levels. The second mechanism is to accompany economic and social expansion by creating projects that operate on clean energy, thus contributing to stopping the volume of emissions to a certain limit. The synchronization of these two mechanisms, if comprehensive in all sectors and widespread in many countries, will play an important role in addressing climate change and maintaining environmental safety.

Some obstacles may impose a slow pace in the spread and production of larger quantities of renewable energy in some countries, perhaps the most important of which is finance and technology, but high-income countries can produce or import these technologies. As we have seen in the literature, the study of Kukharets et al. (2023) recommended that each European country must commit to consuming a percentage of renewable energy that corresponds to the level of its GDP per capita. For example, if the GDP per capita in a country is 10 000 EUR, the percentage of renewable energy consumption there should be 40 % of the total energy consumed, if it is 30 000 EUR, the percentage of renewable energy will be 50 %, and so on. Failure to reach this percentage indicates that there are available untapped potentials, which may be explained by the competitiveness of traditional energy sources in terms of price.

The competitiveness of fossil energy and its dominance on the energy landscape in the sample countries have exerted a positive and strong impact on increasing carbon dioxide emissions in the short and long terms, according to the results of the first model, which agrees with the results of studies by Deka et al. (2023), Madaleno and Nogueira (2023), and Alola et al. (2019).

This competitiveness constitutes a real stumbling block in the path towards renewable energy in low-income countries, and sometimes in high-income countries, especially those that possess traditional energy sources. The sample countries have unique advantages and incentives that may make them pioneers in the transition to renewable energy globally, which are: i) most of them belong to a union governed by binding laws in this context, which members are obligated to implement; ii) the scarcity of traditional energy sources in most of them; iii) the availability of renewable energy sources; iv) most of them lack self-energy security.

The first model also shows the significant contribution of economic growth to increasing CO_2 emissions, supported by the results obtained in the study by Gricar et al. (2022). It is a natural result of the distribution of income between consumption, part of which is allocated to social consumption of traditional energy, and savings, part of which is allocated to investment consumption of fossil energy. Perhaps, the targeting of economic policies in all governments around the world to increase economic growth, based on traditional energy, is an obstacle to addressing the emissions problem.

The results of the second model showed a positive impact of renewable energy on GDP per capita in the short term, supported by the results of Armeanu et al. (2017), Soava et al. (2018), and Madaleno & Nogueira (2023). Nevertheless, its impact on GDP per capita remains weak compared to the impact of other variables, especially fossil energy consumption, capital-labor ratio, and labor. This is explained by the weak share of renewable energy in the total energy consumed in the sample countries.

CONCLUSION

The research examined the relationship among renewable energy, economic growth, and climate change in high-income countries. The ARDL panel methodology was used on European data covering the period 1990–2020. The work focused on questioning the behavior of renewable energy in the face of economic growth and climate change.

Empirical results showed a double positive role of renewable energy in high-income European countries: the first is their effective contribution to reducing CO_2 emissions into the atmosphere, and the second is their contribution to enhancing economic growth. This proves the validity of the first hypothesis, which frames the main question related to this study.

The extracted results also confirmed the impact of economic growth on further exacerbating CO_2 emissions in the sample countries, due to their strong reliance on fossil energy for economic and social uses, which proves the validity of the second hypothesis.

Fossil energy also plays a dual role, the first of which is positive, represented by enhancing economic growth rates, while the second is negative, represented by increasing CO_2 emissions, thus contributing to the further exacerbation of the climate change problem. This proves the validity of the third hypothesis.

It can be concluded that the shift towards clean renewable energy is the ideal solution to address the problem of climate change, and its associated negative effects on environmental safety.It is the key to achieving the goals that the international community has set and is working to achieve, whether within the framework of sustainable development, or in terms of climate agreements, most notably the goal of the Paris Agreement to keep the change in air temperature at a level less than 1.5 degrees Celsius, or other goals such as the goal of zero emissions by the year 2050 according to the International Energy Agency's scenarios.

The results of this study related to high-income European countries can be generalized to the rest of the world's high-income countries, in terms of the behavior of renewable energy in relation to climate and economic growth, as together they are capable of creating a qualitative shift towards the transition from fossil energy to clean energy. However, the matter requires more in-depth research on this topic, such as separating between high-income countries that have an abundance of fossil energy and those that do not, because its availability is among the obstacles to the transition towards renewable energy. It is also possible to distinguish countries that produce renewable energy technologies from those that import them, because importing them increases production costs. These research angles were not investigated in this study.

These results encourage the efforts of European countries to shift from fossil energy to renewable energy, and call for exploiting the incentive represented by the European-Russian conflict following its invasion of Ukraine in order to reduce the dependence on energy from abroad, and push towards achieving energy independence. The study underlines the necessity of playing a locomotive role in this context, by making more research and development efforts in order to reduce the costs of producing clean energy. It must also work to provide support and credit facilities to member states that are less capable of transitioning towards clean energy.

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