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The Relationship Between Economic Growth and CO_2 Emissions in EU Countries: A Cointegration Analysis

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This paper explores the dynamics of the relationship between economic growth and CO_2 emissions in the 27 EU member states in a panel setting for the period 2000–2017. We use qualitative sequential methodology, involving empiric analysis that provides coherence and viability for our study, but also quantitative methods, including Dynamic Ordinary Least Squares (DOLS), unit root tests and cointegration techniques. The results suggest the existence of a long run cointegrating relationship between growth and CO_2 emissions in EU countries and the DOLS method indicates a statistically significant effect of economic growth on CO_2 emissions for both versions of estimators, revealing that on average, a 1% change in GDP leads to 0.072 change in CO_2 emissions. The study also exhibits that higher income levels lead to increased demand for environmental protection and underline the need for designing environmental policies, capable to reduce emissions during periods of economic growth. Moreover, we find that the status of economic growth does not automatically diminish climate vulnerability in EU countries, only the correct type of growth does, thus being necessary that EU policymakers be aware of the energy cost pressure and to achieve economic growth in relationship with appropriate tools in terms of climate risk management.

Keywords: environmental degradation, CO2 emissions, economic growth, cointegration analysis, climate risk

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1 INTRODUCTION

Climate change and environmental degradation influence the status of the sustainable economy, being affected both financial and non-financial institutions (Haigh 2011; Sullivan 2014; Ozili, 2020). The potential negative implication of climate change on economic activity is revealed by the climate risk which leads to adverse impacts on human livelihoods and well-being. Managing climate risks and facing up to losses and damages, implies societal decisions, proactive management, and the capacity to predict climate dynamics related to the future greenhouse gas emission and of course, to the entire pattern of socio-economic development and equality. Emissions from human industry represent a key factor in climate change and exhibit one of the world's most pressing challenges. Year by year increase the concentration of carbon dioxide in the atmosphere and even if energy is a fundamental engine of economic development, the evolution of demand at different stages of economic development requires a viable solution for environmental problems. According to the literature insights, there are different types of approaches and different hypotheses related to the relationship between economic growth and environmental pollution. On the one hand, it is revealed that the status of environmental quality is influenced by the level of per capita income, which generate changes in environmental policies and legitimize the assumption that the higher is per capita income, the higher will be environmental deterioration. On the other hand, it is assumed that the ability to manage climate stress depends on the level of economic growth and is strongly influenced by the status of the financial sector, well-designed institutions, health sanitation system and the levels of education. At the EU level, environmental problems have escalated and even if the implemented environmental policies have brought some benefits, the use of natural resources linked to economic growth continued to pressure the environment and lead to new challenges and vulnerabilities in climate change areas.

Though there are numerous studies analyzing the dynamics of the relationship between growth and CO_2 emissions, only few focus on the profile of EU countries, losing sight of the largest contribution of the European Union to the global greenhouse gas emissions. EU strategies intend to remove more carbon emissions from the air, but the efforts are even harder and more demanding considering that in the year 2020 the European Union produced approximately 2.54 billion metric tons of carbon dioxide emissions.

Even if the EU has adopted ambitious climate law frameworks, such as Paris Climate Agreement, the Kyoto protocol for EU 15 or the European Climate Law from 2021 which promote the goals set by the European Green Deal, still remains the group of countries with a large contribution to the global greenhouse gas emissions. Paris Climate Agreement of 2015, entered into force in 2016 and impose limits in terms of global warming, Kyoto protocol for EU 15 aimed to reduce greenhouse emission and the European Climate Law from 2021 promote the goals set by the European Green Deal which stipulate the necessity to achieve climate neutrality by 2050 an to reduce CO_2 emissions by 55% by 2030 compared to 1990. However, according to statistics of the European Commission, in most EU Member States, in the third quarter of 2021, it is highlighted an increase in greenhouse gas emissions compared with the same quarter of 2020. Therefore, in the light of concerns related to the economic growth framework and due to the fact that the growth of many national economies cannot be delimited by an increase in greenhouse gas emissions, we investigate a vital issue related to climate change, respectively, the relationship between real GDP and CO_2 emission across EU countries. We use panel data from the 2000 to 2017 and we document that there is a positive correlation between real GDP and CO_2 emission. The results suggest that higher income levels lead to increased demand for environmental protection and underline the need for designing environmental policies, capable to reduce emissions during periods of economic growth. We exhibit that the status of economic growth does not automatically diminish climate vulnerability in EU countries, only the correct type of growth does.

The methodological approach includes qualitative sequential methodology, involving empiric analysis that will provide coherence and viability for our study, but also quantitative methods such as Dynamic Ordinary Least Squares (DOLS), unit root tests and cointegration techniques. As a first step, we establish the state of affairs and based on the content analysis we build a concrete image in terms of key characteristics of green infrastructure research and the correlation between growth and CO_2 emission by focusing on the countries of the European Union. Second, we focus on empirical analysis of the relationship between carbon dioxide (CO_2) emissions and economic growth. And as a final step, we establish the status of convergence to global policy incentives, and we identify new mechanisms and instruments for the purpose of reducing CO_2 emissions while attaining economic growth in EU countries.

The study provides new evidence on a panel of EU countries and based on Dynamic Ordinary Least Squares (DOLS), unit root tests and cointegration techniques, empirically analyzed the relationship between economic growth and CO_2 emissions. The study has a broader coverage and represents an important contribution to the extant literature based on three important contributions: First, it adds to the growing body of empirical investigations on the determinants of reducing CO_2 emissions while attaining economic growth, especially to the literature studying the impact of economic growth on environmental degradation. Second, we identify the literature gap, and we highlight that only a few studies focus on the profile of EU countries, losing sight of the largest contribution of the European Union to the global greenhouse gas emissions and we disentangle the implication of economic growth on CO_2 emissions on the profile of EU countries. We document a statistically significant effect of economic growth on CO_2 emissions for both versions of estimators and we emphasize that this effect is driven especially by the energy cost pressure and inefficiency in working with appropriate tools in terms of climate risk management. Third, we provide more insights into the relationship between higher income levels and the demand for environmental protection and we underline the need for designing environmental policies, capable to reduce emissions during periods of economic growth. The study also offers a clearer picture of EU energy cost pressure and represents a valuable framework for academics, practitioners, decision-makers and governments from the EU level. The remainder of the paper is structured as follows: In **Section 2** we review the current discussion on the relationship between CO_2 emissions and economic growth, in **Section 3** we present the sample, data and econometric framework; in **Section 4** we discuss the empirical results and in **Section 5** we conclude.

2 LITERATURE REVIEW

During the last two decades, has increased the interest in analyzing growth policies in relation to climate change, global warming and the greenhouse effect being the core of the analysis. The economic literature on CO_2 Emissions and growth is becoming abundant but decreased when we consider the studies that analyse the relationship between economic growth and CO_2 emissions in EU countries. Despite the large number of studies that have examined the status of climate change and global warming, there are only a few studies that have investigated the relationship between economic growth and CO_2 emission, especially in the profile of EU countries. The energy growth paradox is usually analyzed from the perspective of damage to the biosphere and although there are studies suggesting that energy contributes to economic growth (Shahbaz et al., 2013; Azam et al., 2020; Baz et al., 2021; Magazzino et al., 2021; Zhang et al., 2021) we also find studies demonstrating that energy has a negative impact on economic growth (Garcia1 et al., 2020).

In the debates carried out under the rubric of creating a "correct type of growth" that should be related to the objective of reducing CO_2 emissions, most of the papers analyzed the relationship between economic growth and CO_2 emissions. Azam et al. (2016) analyse the environment degradation proxied by CO_2 emission on the profile of selected higher CO_2 emissions economies and conclude that there is a positive relationship between CO_2 emissions and economic growth in China, Japan, and the USA. For BRIC countries, Li 2022 and Pao and Tsai (2010) reveal that in the long-run equilibrium, energy consumption has a positive and statistically significant impact on CO_2 emissions. A number of studies examined the relationship between CO_2 emission and economic growth at the country level, an example is Yousefi-Sahzabi et al. (2011) who investigate the relationship between CO_2 emission and economic growth of Iran and confirms a positive strong correlation between CO_2 emission and economic growth and related to this point of view, Bouznit and María del (2016) also confirm the same results on the profile of Algeria and Lešáková and Ondřej (2018) on the profile of Czech Republic. For Israel, Magazzino (2015) highlights that the real gross domestic product (GDP) drives both energy use and CO_2 emission. Some studies such as those of Kluschke et al. (2019) and Delgado and Lutsey (2015) analyse the status of CO_2 emission and related costs for various technology. Song and Xu (2012) compare the emissions from two alternatives, more exactly, analyse the emission between direct and feeder liner services and conclude that shipping companies should be useful to consolidate policy merits and service route design from a CO_2 emissions perspective.

Performing a literature overview, we find few studies examined the major factors affecting CO_2 emission or analysed the instruments for the purpose of reducing CO_2 emissions while attaining economic growth in EU countries. Recent studies validate the existence of a global interrelationship between economic growth and carbon dioxide emissions (Fávero et al., 2022; Khan et al., 2022). Bengochea-Morancho et al. (2001) explores the relationship between economic growth and CO_2 emission on a panel of ten European Union countries for the period 1981–1995 and conclude that there are major differences in terms of strategies to control emissions, indicating the necessity to manage the reduction of emissions by considering the economic situation of each EU countries. However, Acaravci and Ozturk (2010) admit the heterogeneity of EU countries and based on autoregressive distributed lag (ARDL) bounds test the approach of cointegration for nineteen European countries revealing that there is a causal relationship between CO_2 emissions, energy consumption and economic development in only seven from nineteen countries. Bilan et al. (2019) analyse the implication of renewable energy sources and CO_2 emission on GDP and confirms the existence of the relationship between the analysed variables, linked to this point of view, Halicioglu (2009) also validate that economic growth is closely related to energy consumption and the increase in growth leads to higher CO_2 emissions. In terms of instruments to reduce greenhouse emissions, according to Dogan and Seker (2016), it is highlighted that environmental pollution can be reduced by increasing the share of renewable energy. Other studies such as those of Breed et al. (2021) emphasize that based on the fact that one-quarter of the energy-related greenhouse gas emissions are from transport, fuel economy regulation can be a powerful instrument to reduce CO_2 emissions. At the global level, Jiang and Guan (2016), analyse the determinants of CO_2 emission growth and conclude that the CO_2 emissions from coal use grew the most rapidly and the growth in final demands has led to significant CO_2 growth worldwide.

Energy represents an essential engine of progress and economic development, which directly affect our essential well-being (Mendonç et al., 2020). Therefore, the ability to consolidate environmental sustainability and manage climate stress depends on the public agenda strategies and the entire itinerary of economic development. Economic activity and the technology status influence, of course, the energy demand and even if energy is an essential engine of economic growth, the negative implication on wellbeing can be managed by reducing vulnerability and promoting the right type of growth. A study conducted in 2017 on 31 developing countries, aimed to identify the effect of economic growth on CO_2 emission. Using a dynamic panel threshold framework, the authors show that there is a significant link between growth and CO_2 emission, highlighting that economic growth has a negative effect on CO_2 emission in the low growth regime but a positive effect in the high growth regime (Goodness and Prosper, 2017). Moreover, the study identifies methods to consolidate sustainable economic growth without increasing the level of emission, by highlighting the need to switch away from non-renewable energy to renewable energy. Linked to these results, many researchers have agreed that imposed mechanisms for increasing renewable energy had decreased CO_2 emissions (Cosmas et al., 2019; Toumi and Toumi, 2019). Moreover, the most recent studies examine if it is tough for CO_2 emission reduction to be compatible with the goal of economic growth and conclude that energy contributes to economic growth (Shahbaz et al., 2013; Azam et al., 2020; Baz, Khan et al., 2021; Magazzino et al., 2021; Zhang et al., 2021) and contrary to this point of view, we also find studies demonstrating that energy has a negative impact on economic growth (Garcia1 et al., 2020). Overall, the stream of the literature review reveals on the one hand, that growth per se could reduce climate vulnerability and economic vulnerability to disasters decreases as income increases, on the other hand, it is highlighted that CO_2 emissions depend on the amount of money we have, meaning that the richer we are, the more CO_2 we disengage. By retrospective analyze the existing literature, we can conclude that few studies focused on the profile of EU countries and this gap in the literature inspired the itinerary of this study, meaning to investigate a vital issue related to climate change, respectively, the relationship between real GDP and CO_2 emission across EU countries.

3 SAMPLE, DATA, AND METHODOLOGY

3.1 Sample and Data

We study the dynamics of the relationship between economic growth and CO_2 emissions in the 27 EU member states in a panel setting for the period 2000–2017. We use qualitative sequential methodology, involving empiric analysis that provides coherence and viability for our study, but also quantitative methods, including Dynamic Ordinary Least Squares (OLS) (DOLS), unit root tests and cointegration techniques. Gaining insight into what literature gives us, we find that the main advantage of the panel cointegration approach is its focus on the long-run relationships, and the format of the models limits the number of the accounted variables typically to CO_2 emissions and GDP per capita (Martinez-Zarzoso and Bengochea-Morancho, 2004; Lean and Smyth, 2010; Arouri et al., 2012; Kapusuzo˘glu 2014; Zhang et al., 2021). Therefore, given that economic growth is one of the most-watched economic indicators and usually is the core of the economic research analysis, it has been included in the analysis. Besides, represent an indicator that can be related to the trend in the capacity of an economy to produce goods and services in a period compared to another one. To measure the increase in the production of goods and services in EU economies, we use the most common indicator GDP Per Capita (constant U.S. $). Additionally, the growth process requires energy consumption and leads to rising atmospheric concentrations of carbon dioxide, that's why we include in the analysis the status of carbon emissions, measured by CO_2 Emissions (metric tons per capita).Other variables included in the analysis are: the rate of population growth, gross savings which represent the difference between disposable income and consumption and gross fixed capital formation (formerly gross domestic fixed investment) which includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. The main source of data is the database of the World Bank, World Development Indicators. The conceptual framework is explained in the next part of the study.

3.2 Econometric Framework

3.2.1 Panel Unit Root Tests—Methodology

According to the literature, there are two types of panel unit root tests. The first one can be classified as first-generation, has as particular limit the assumption of cross-sectional independence and incorporate Levin-Lin-Chu test-LLC (Levin A. et al., 2002), Im-Pesaran and Shin test-IPS (Persan et al., 2003) and Fisher-type tests. The second one is named the second generation and rejects the cross-sectional independence hypothesis. The previously mentioned tests represent the extension of the classical ADF unit root test (Augmented Dickey-Fuller) and can be expressed by the following equation:

$$\Delta y_t = \rho_{y_{t-1}} + \sum_{p=1}^{P} \phi_p \Delta y_{t-p} + \gamma_l' D_l + \varepsilon_t, t = 1, ..., T \qquad (1)$$

The Augmented Dickey-Fuller tests the null hypothesis that $\mathcal{Y}t$ has the unit root, versus the alternative that $\mathcal{Y}t$ is stationary (H_0: $\rho = 0$ against H_1: $\rho < 0$). For panel case, the Augmented Dickey-Fuller test is accomplished by running the following equation:

$$\Delta y_{i,t} = \rho_i \mathcal{Y}_{i,t-1} + \sum_{p=1}^{P_i} \phi_{ip} \Delta y_{i,t-p} + \gamma_{li}' D_{li} + \varepsilon_{i,t}, t = 1, \ldots, T, \quad i = 1, \ldots, N \qquad (2)$$

Eq. 2 develop the first equation, and it considers that the errors $\varepsilon_{i,t} \sim N(0, \sigma^2)$ are assumed to be independent across the individuals. The Levin-Lin-Chu test assume the null H_0: $\rho_i = \rho = 0 \; \forall_i$ against *the alternative*H_1: $\rho_i < 0 \; \forall_i$. The Im-Pesaran and Shin test-IPS (Persan et al., 2003), in contrast to LLC test, admit the probability of varying autoregressive processes across individuals and can be expressed by the following equation:

$$\bar{t}\, NT = N^{-1} \sum_{i=1}^{N} t_{iT} (P_i, \phi_{i1}, \ldots, \phi_i P_i) \qquad (3)$$

In which case t_{iT} $(P_i, \phi_{i1}, \ldots, \phi_i P_i)$ represent the t-statistic for assessing the unit root in the ith individual process. P_i represent the lag order which is generally selected based on some info criterion and $\bar{t}\, NT$ is included to test the null hypothesis H_0: $\rho_i = \rho = 0 \; \forall_i$, against the alternative H_1: $\exists i \in \{1, \ldots, N\}$, $\rho_i < 0$.

With reference to second generation unit root tests, we follow the assumption of the Cross-sectional Im-Pesaran-Shin test (CIPS), proposed by Pesaran (2007), which alternatively to standard ADF, adds lagged cross-sectional means of individuals $\bar{\mathcal{Y}}_t$ and is accomplished by running the following equation:

$$\Delta y_{i,t} = \rho_i \mathcal{Y}_{i,t-1} + \varphi_i \bar{\mathcal{Y}}_{t-1} + \psi_i \Delta \bar{\mathcal{Y}}_t + \gamma_{li}' D_{li} + \varepsilon_{i,t}, t = 1, \ldots, T, \quad i = 1, \ldots, N \qquad (4)$$

The Cross-sectional Im-Pesaran-Shin statistic is estimated as group mean of t statistics obtained from Cross-sectional Augmented Dickey-Fuller equations, the rationale being explained in **Eq. 3**.

3.2.2 Cointegration Analysis—Methodology

To explore the relationship between CO_2 emission and economic growth in EU countries we follow the empirical literature, and we perform cointegration tests, thus investigating the existence of long run relationship among the variables (Pedroni 1999; Kao, 1999; Pedroni 2000; Pedroni 2001; Pesaran 2004; Pesaran 2007; Narayan and Smyth, 2008; Al-Mulali, 2011; Al-Mulali, 2012; Mitic et al., 2017). Comparable to panel unit root tests, panel cointegration tests are more effective and powerful than the traditional time series cointegration. First, we follow cointegration testing and Granger causality testing and then based on literature validation we develop a clear modelling approach based on panel Dynamic Ordinary Least Squares (DOLS) estimation methods in the existence of cointegration (see. Mikayilov et al., 2018; Zoundi, 2017). According to literature insights, the granger causality test represents an important instrument for detecting the dynamic interrelationships between two groups of variables (Bai et al., 2018), the methodology being applied at the institutional level, and being used in evidence from Linear and Nonlinear Panel and Time Series Models (see Chow et al., 2018).

The panel cointegration tests of Pedroni (Pedroni, 2004) is given by **Eq. 3**.

$$\mathcal{Y}_{i,t} = \beta_i' x_{i,t} + \gamma'_{li} D_{li} + \varepsilon_{i,t}, \text{ where } x_{i,t} \textit{ is equal to } x_{i,t-1} + \varepsilon_{i,t} \quad (5)$$

Panel Dynamic Ordinary Least Squares (DOLS) represents a measurement tool for predicting a particular cointegrating vector in the panel, the rationale of DOLS model requires that the variables be cointegrated. The model has the following specification:

$$\mathcal{Y}_{i,t} = \beta_i' x_{i,t} + \sum_{j=-q}^{q} \zeta_{ij} \Delta x_{i,t+j} + \gamma'_{li} D_{li} + \varepsilon_{i,t} \quad (6)$$

Where q denoting the number of lags normally chosen based on some info criterion. The effectiveness of these methods is given by the advantage of controlling the endogeneity in the model, thus providing robust correction of endogeneity in the explanatory variables (Mark and Donggyu, 2003; Dritsaki and Dritsaki, 2014). To test the general notion from Solow growth model theory and to assess the implication of general theory which admits that high population growth leads to lower per capita output, we used ordinary least-squares regression model (OLS) analysis with the following specification:

$$GDPCAP_{it} = c_0 + c_1 \times POPGR_{i,t} + u_{i,t}, \quad (7)$$

Where i and t indicate the country and year for each variable. The dependent variable $GDPCAP_{it}$ represents a key metric for assessing the increase in the production of goods and services in EU economies. The independent variable includes the rate of population growth, $POPGR_{i,t}$. Moreover, to evaluate the theoretical determinants of economic growth, the following models include relevant explanatory variables that influence the level of economic growth:

$$GDPCAP_{it} = c_0 + c_1 \times POPGR_{i,t} + c_2 \times CO2_{i,t} + c_3 \times GS_{i,t} + c_4 \times GFCFS_{i,t} + u_{i,t}, \quad (8)$$

Where i and t indicate the country and year for each variable. The dependent variable $GDPCAP_{it}$ and the first independent variable are analogous to those indicated in **Eq. 7**. Other independent variable includes the status of carbon emissions, measured by CO_2 Emissions (metric tons per capita), $GS_{i,t}$ which measure gross savings and represent the difference between disposable income and consumption, $GFCFS_{i,t}$, which measure gross fixed capital formation (formerly gross domestic fixed investment) and includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings.

The fixed-effects model has the following form:

$$Y_{i,t} = \alpha_i + X_{i,t} \times \beta + \varepsilon_{i,t}, \quad (9)$$

$Y_{i,t}$ represents the dependent variable for country i at time t, α_i represents an unknown country-specific constant, $X_{i,t}$ indicates the time-variant regressor matrix, and $\varepsilon_{i,t,}$ is the error term; in order to validate the appropriateness of the fixed-effects model, the Hausman test was performed.

4 EMPIRICAL RESULTS

To avoid the implication of spurious results, we applied unit root tests and we verify the stationarity of data. We run Levin et al. (2002), Im et al. (2003), and Fisher-type tests for each variable and we test the unit root. The benchmark results listed in **Table 1** and **Table 2** reveal the results for unit root tests, which has been applied in level and the first difference with intercept, in intercept and trend or none of them incorporated in the test equation separately. Following the literature validation, when is run the ADF test, it is required to check both versions-with intercept only and intercept and trend (Al-Mulali, 2011).

The results of panel unit root tests reported in **Tables 1**, **2** clearly reveal that running Levin et al. (2002), Im et al. (2003), and Fisher-type tests we obtain mixed results at the level order. However, when we analyse the results of the panel unit root in first differences, the null hypothesis could be rejected, and the results indicate that all the panels are stationary. For GDP, the outcomes for unit root analysis exemplify that at the level, in most of case, the variable has unit root, but when we apply the first difference it becomes stationary. The Unit Root Test of Carbon Emission Variable (CO_2) reveals similar results, as Levin, Lin & Chu, Im, Pesaran and Shin, ADF—Fisher Chi-square and PP—Fisher Chi-square show non-stationarity in levels and stationarity in differences. The overview of the results is validated by literature background, studies such as those employed by Gün (2019), Mitić et al. (2017), Bastola and Sapkota (2014), Arouri et al. (2012), revealing similar results, the same variables not being stationary at the level but stationary at first difference. Once we established that both variables are stationary, we conduct panel cointegration tests and we focus on empirical analysis of the relationship between carbon dioxide (CO_2) emissions and economic growth. **Table 3** exhibits the estimation results for panel cointegration tests.

The overview of the results reveals that for the Pedroni test within-dimension when an intercept is included, the null hypothesis of no cointegration is rejected for two of the four tests for the panel statistics. For the Pedroni test within-dimension, when an intercept and a trend is included, it seems that for all four panels the null hypothesis is rejected, and it is cointegration between the variable. Overall, for most of the tests applied, the null hypothesis is rejected, and the results reveal that the variables are cointegrated and are moving together in the long run. Next, whereas the variables are cointegrated, we strengthen the quality of the research and we run the DOLS estimator. Estimation of cointegrating relationship between CO_2 emission and economic growth is reported in **Table 4**. Panel Dynamic Ordinary Least Squares (DOLS), represent a measurement tool for predicting a particular cointegrating vector in the panel, the rationale of the DOLS model requires that the variables be cointegrated.

Employing the DOLS estimator, we test the consistency of the results. The results from this estimation technique validate the existence of a long-run cointegration relationship between the emissions-economic growth. The positive relationship between the variables reveals that the higher is GDP, the higher will be CO_2 emissions in the EU countries. Estimation of cointegrating relationship through the DOLS method indicates a statistically significant effect of economic growth on CO_2 emissions in EU countries for both versions of estimators, revealing that on average, a 1% change in GDP leads to 0.072 change in CO_2 emissions on the profile of EU countries.

TABLE 1 | Unit root test of GDPCAP variable (GDPCAP).

	Level			First difference		
	Intercept	Intercept and trend	None	Intercept	Intercept and trend	None
Levin, Lin and Chu t	−8.10252 (0.0000)	−4.52672 (0.0000)	4.00107 (1.0000)	−9.85924 (0.0000)	−14.9930 (0.0000)	−12.9081 (0.0000)
Im, Pesaran and Shin	−3.321 (0.0004)	2.87412 (0.9980)	—	−7.87314 (0.0000)	−13.5794 0.0000	—
ADF—Fisher Chi-square	82.5761 (0.0074)	20.2582 (1.0000)	8.42745 (1.0000)	158.615 (0.0000	250.207 (0.0000)	218.488 (0.0000)
PP—Fisher Chi-square	98.3635 (0.0002)	8.03519 (1.0000)	5.81127 (1.0000)	195.789 (0.0000)	328.435 (0.0000)	274.610 (0.0000)

Note: Null hypothesis: Unit root (individual unit root process). Probabilities are given between parentheses.

TABLE 2 | Unit root test of carbon emission variable (CO_2).

	Level			First difference		
	Intercept	Intercept and trend	None	Intercept	Intercept and trend	None
Levin, Lin and Chu t	0.52688 (0.7009)	−1.6060 (0.0541)	−6.01321 (0.0000)	−4.30457 (0.0000)	−10.7501 (0.0000)	−10.82 (0.0000)
Im, Pesaran and Shin	3.39085 (0.9997)	0.07599 (0.5303)	—	−5.85093 (0.0000)	−2.32091 (0.0000)	—
ADF—Fisher Chi-square	22.6611 (0.9999)	47.5118 (0.7212)	100.518 (0.0001)	126.555 (0.0000)	80.6774 (0.0095)	203.116 (0.0000)
PP—Fisher Chi-square	30.5891 (0.9957)	90.0386 (0.0015)	90.7524 (0.0013)	369.295 (0.0000)	290.799 (0.0000)	429.249 (0.0000)

Note: Null hypothesis: Unit root (individual unit root process). Probabilities are given between parentheses.

TABLE 3 | Panel cointegration tests.

Dimension	Test statistics	Intercept		Intercept and trend	
		Statistic	Prob.	Statistic	Prob.
Within-dimension	Panel v-statistic	−2.2955	0.9891	1.7025	0.0443
	Panel rho-statistic	1.1202	0.8687	−14071	0.0797
	Panel PP-statistic	−2.2004	0.0139	−5.5743	0.0000
	Panel ADF-statistic	−4.0313	0.0000	−1.8520	0.0320
Between-dimension	Panel rho-statistic	3.1372	0.9991	0.9244	0.8224
	Panel PP-statistic	−0.5455	0.2927	−4.7699	0.0000
	Panel ADF-statistic	−2.5727	0.0050	−0.6319	0.0263
		Kao residual cointegration test			
ADF	t-statistic		Prob.		
	2.76692		0.0028		

Note: Null hypothesis: No cointegration. Trend assumption: no deterministic trend and Deterministic intercep and trend. Probabilities are given between parentheses.

TABLE 4 | Estimation of cointegrating relationship.

Estimation method	DOLS			
	Pooled		Grouped	
	Coefficient	Prob.	Coefficient	Prob.
Long-run coefficient	0.0730	0.0313	0.0726	0.0000
No. of observations	405			
R-squared adj.	0.9541			

Note: Dynamic OLS; OLS, ordinary least squares.

The results reveal that related to the status of convergence to global policy incentives, EU countries remain the group of countries with a significant contribution to worldwide greenhouse gas emissions and even if it has adopted an ambitious climate law framework, it is in search of new mechanisms and instruments for the purpose of reducing CO_2 emissions while attaining economic growth. The presence of a long-term relationship between environmental degradation and economic growth, reveals the necessity to develop a pivotal strategy for reducing CO_2 emissions and implement modern technologies for CO_2 capture and storage. From the perspective of strengthening the waste management strategy, we can exemplify: an increased analysis of the emissions trading system in all sectors, better forest management and increasing forested areas, facilitating the transition to electric and hybrid vehicles, as well as tightening emission standards for cars. The legislative instrument can also directly contribute to reducing CO_2 emissions and focusing on environmental regulations and taxes and emission reduction taxes could create support for managing the growing volume of CO_2 emissions.

Additionally, given that the nature of the long-run relationship between growth and carbon emission can be better understood if we examine the factors behind the observed relationship, we also

TABLE 5 | Panel data stationarity test estimates—Hadri and Larson.

Variables	Zt	*p*-value
Income growth	1.93391	0.0266
Saving rates (Gross savings)	6.24772	0.0000
Population growth	6.12319	0.0000
CO_2 emission	9.631448	0.0000
Gross fixed capital formation	6.24772	0.0000

Note: Null hypothesis: Unit root (individual unit root process). Probabilities are given between parentheses.

TABLE 6 | Cointegration test estimates for the Solow model.

Test type	Statistic	Probability
$Kao : D - F_\rho$	−6.625983	0.0000
$Kao : D - F_{t\rho}$	−5.846188	0.0000
$Pedroni_\rho$	2.733909	0.0053
$Pedroni_{t\rho}$	1.642403	0.0531

evaluate the Solow Growth Model and we included in the analysis other variables, such as income growth, gross savings, carbon emissions, gross fixed capital formation and population growth. Therefore, we follow the econometric literature, and we perform the panel data unit root tests for analysing the null hypothesises which refers to the non-stationarity of the time series and for this time, we follow Strauss and Yigit (2003) point of view and we carry out the potentially biased problems of Im, Pesaran, and Shin panel data unit root test. The results of Hadri tests are reported in **Table 5**. As can be seen, the results confirm that the null hypotheses of stationarity of all panels under individual heteroscedasticity and time series correlation can be rejected and reveal that EU countries have their growth variables guided by the unit root process.

Next, we follow Kao's (1999) and Pedroni's (1999, 2000) points of view and we perform the cointegration test with the null hypothesis regarding the estimated equation as not cointegrated. Therefore, we first perform the Dickey-Fuller t-based test ($Kao : D - F_\rho$), then we test the implication of the augmented Dickey-Fuller t-based test Kao: (D-F-tρ). Finally, we calculate the Pedroni tests. The results reported in **Table 6** highlight the hypothesis of cointegration between the variables and support the idea that the analysed variables have one common trend that combines them in the long run.

As a final step, following the rationale of Solow Growth theory and taking into account that general theory admits that high population growth leads to lower per capita output, in **Table 7** we report the results for testing this theory by regressing gross domestic product per capita relative to the EU countries on the rate of population growth. According to model 2, it is revealed that the effect of population growth is strong and statistically significant. It seems that the results for this simple regression, support the theory and reveal that population growth appears to have a very large negative effect on economic growth.

Furthermore, in model 1 we included other variables such as CO_2 emission, gross savings and gross fixed capital formation and we found that energy consumption together with gross fixed capital has a positive and statistically significant impact on economic growth in the long run, the results being similar to those obtained by Streimikiene and Kasperowicz (2016).

5 DISCUSSION

This paper seeks to fill a gap in the extant literature by exploring the causal relationship between economic growth and CO_2 emissions in EU countries. Cointegration analysis for EU economies was conducted using the DOLS approach developed by Pedroni (2004) and Kao (1999), respectively. First, we follow cointegration testing and Granger causality testing and based on the methodology promoted by Mikayilov et al. (2018), Zoundi (2017), we develop a clear modelling approach based on panel Dynamic Ordinary Least Squares (DOLS) estimation methods in the existence of cointegration (Zoundi, 2017; Mikayilov et al., 2018). The results perspicuously suggest the existence of a long run cointegrating relationship between growth and CO_2 emissions in EU countries and the DOLS method indicates a statistically significant effect of economic growth on CO_2 emissions for both versions of estimators. These results are consistent with the recent work of Fávero et al. (2022), Khan et al. (2022), which validate the existence of a global interrelationship between economic growth and carbon dioxide emissions. The main difference between previously mentioned studies and our research is that estimates static and dynamic contemporaneous relationships of GDP and CO_2, while our work provides long-run cointegration assessment. The multilevel approach conducted by Fávero et al. (2022), also includes interactions between fixed and random effects parameters regarding GDP and carbon dioxide emissions.

The literature survey on the empirical relationship between economic growth and CO_2 emission is vast and controversial, the main problem in terms of empirical validity was always related to the lack of diagnosis of the stationarity properties of the variables, and in a panel data context, the presence of cross-sectional dependence. Therefore, we take into consideration both criticisms, we use recent unit root tests and cointegration techniques that are robust to the presence of cross-sectional dependence. **Tables 1**, **2** reveal the results for Levin et al. (2002), Im et al. (2003), and Fisher-type tests for each variable, the unit root tests have been applied in level and the first difference with intercept, in intercept and trend or none of them incorporated in the test equation separately. If we analyse the results of the panel unit root in the first differences, the null hypothesis could be rejected, and the results indicate that all the panels are stationary. Our findings are consistent with the work of Bastola and Sapkota (2014), Mitić et al. (2017), Gün (2019), and Arouri et al. (2012), which reveal similar results, the same variables not being stationary at the level but stationary at first difference. From **Table 3**, we find that the economic growth and growth in emissions go hand in hand and the variables are cointegrated and are moving together in the long run. Moreover, applying the DOLS estimator we test the consistency of the results, and we validate the existence of a

TABLE 7 | The results of mixed-effect model.

Variables	**Model 1**		
	Pooled OLS	**Random effect**	**Fixed effect**
Population growth (POPGR)	−1.076 (5.12)**	−1.189 (4.67)**	−1.677 (4.44)**
CO_2 emisiion (CO_2)	−0.003 (0.05)	(0.003) (0.05)	0.079 (0.55)**
Saving rates (Gross savings) (GS)	−0.000 (2.27)*	−0.000 1.42	−0.000 (0.13)
Gross fixed capital formation (GFCF)	0.303 (7.62)**	0.334 (7.72)**	0.404 (7.49)**
Cons	−4.044 (4.19)**	−4.784 (4.42)**	−5.748 (4.14)**
Hausman		5.47***	
N	484	484	484
R2	0.43	0.48	0.51
Variables		Model 2	
	Pooled OLS	Random Effect	Fixed Effect
Population growth (POPGR)	−1.021 (3.97)**	−0.684 (1.81)	−1.021 (3.97)**
Cons	2.514 (9.67)**	2.442 (13.51)**	2.514 (9.67)**
Hausman		(14.9)**	
N	486	486	486
R2	0.36	0.38	0.40

*Source: Research results. Notes: the results include the coefficient of variable and *t statistic results in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.*

long run cointegration relationship between the carbon emissions and economic growth, meaning that on average, on the profile of EU countries, 1% change in GDP leads to 0.072 change in CO_2 emissions. Consequently, our results provide some important information on the directional predictability between economic growth and CO_2 emissions. First, the findings indicate that higher income levels lead to increased demand for environmental protection and underline the need for designing environmental policies, capable to reduce emissions during periods of economic growth. Of course, the status of economic growth does not automatically diminish climate vulnerability in EU countries, only the correct type of growth does. Second, given that emissions trading and economic incentive approaches are generally unpopular with some environmental analysts due to the impression of "polluter pays", we highlight the need to consolidate the efficiency of emissions trading systems. Third, the study reveals that even if several factors contribute to global warming, carbon dioxide (CO_2) emissions are particularly important, suggesting that EU economies need to follow global policy incentives, and try to implement new mechanisms and instruments for the purpose of reducing CO_2 emissions, such as taxes on environmentally harmful behavior, improved forest management and in general increasing areas of the Earth covered in forests, and facilitating the transition to electric and hybrid vehicles, as well as tightening emission standards for cars. Besides, the understanding of this relationship between environmental quality and economic growth is important for identifying appropriate policies for sustainable development. Therefore, it is necessary that EU policymakers be aware of the energy cost pressure and achieve economic growth in relationship with appropriate tools in terms of climate risk management.

It is of the utmost importance to emphasize that the nature of the long-run relationship between growth and carbon emission can be better understood if we observe the factors behind the observed relationship, meaning that it is important to have an overview of efficiency in terms of allocation of resources in European economies, analyse the costs for various technology, analyse investments in the modernization of production processes. There are two major limitations in this study that could be addressed in future research. First, considering that only a few studies focus on the profile of EU countries, losing sight of the largest contribution of the European Union to the global greenhouse gas emissions, it is required to solve the lack of previous research studies and to continue research on this topic. Second, in the context of future research, new variables can be introduced into the CO_2 emissions and economic growth nexus, such as energy consumption, renewables, environmental awareness, environmental sustainability index or technological development.

6 CONCLUSION

Global warming represents a concern for everyone, and governments are looking for effective ways to reduce the dangerous climate change. Several factors contribute to global warming, but carbon dioxide (CO_2) emissions are particularly important. This study is about identifying the potential nexus between the environment and economic growth, the subject is highly studied and of particular importance for policy makers, academia, and industry alike. Considering that the direct consequence of pollutant emissions is climate change and global warming, the principal aim of this study was to assess the causal relationships between economic growth and carbon emissions in European countries, from the period 2000 to 2017. The study has a broader coverage and represents an important contribution to the literature by the fact that it adds to the growing body of empirical investigations on the determinants of reducing CO_2 emissions while attaining economic growth, especially to the literature studying the impact of economic growth on environmental degradation. Moreover, we identify the literature gap, and we highlight that only a few studies focus on the profile of EU countries, losing sight of the largest contribution of the European Union to the global greenhouse gas emissions and we disentangle the implication of economic growth on CO_2 emissions on the profile of EU countries. Additionally, we provide more insights into the relationship between higher income levels and the demand for environmental protection and we underline the need for designing environmental policies, capable to reduce emissions during periods of economic growth. We used qualitative sequential methodology, involving empiric analysis that provides coherence and viability for our study, but also quantitative methods, including Dynamic Ordinary Least Squares (DOLS), unit root tests and cointegration techniques. The main source of data was the database of the World Bank, World Development Indicators.

Panel unit root tests have been applied in level and in the first difference with intercept, in intercept and trend or none of them incorporated in the test equation separately. The results reveal that running Levin et al. (2002), Im et al. (2003), and Fisher-type tests we obtained mixed results at the level order, but when we analyzed the results of the panel unit root in first differences, the null hypothesis was rejected, and the results indicate that all the panels are stationary. For both GDP and carbon emission it is validated the presence of stationarity differences. As a second step, after we established that both variables are stationary, we conduct panel cointegration tests and we focus on empirical analysis of the relationship between carbon dioxide (CO_2) emissions and economic growth. Cointegration analysis for EU economies was conducted using DOLS approach. We find that the status of economic growth does not automatically diminish climate vulnerability in EU countries, only the correct type of growth does, thus being necessary that EU policymakers be aware of the energy cost pressure and achieve economic growth in relationship with appropriate tools in terms of climate risk management.

The results confirm the existence of a statistically significant long run cointegration relationship between economic growth and CO_2 emissions, revealing that on average, a 1% change in GDP leads to a 0.072 change in CO_2 emissions. The fact that the variables are cointegrated and are moving together in the long run, reveals the necessity to strengthen the waste management strategy, and better analyze the pollutant emissions which directly influence climate change and global warming. The study also demonstrates that higher income levels lead to increased demand for environmental protection and underline the need for designing environmental policies, capable to reduce emissions during periods of economic growth. Additionally, increasing the efficiency in the allocation of resources and adopting instruments capable to direct consumers to the use of renewable energies must be the core of the European public agenda (Kao, 1999; Ozturk, 2010; Aye and Edoja, 2017; Lešá ková and Dobeš, 2020).

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://databank.worldbank.org/home.aspx.

AUTHOR CONTRIBUTIONS

MO, AV, and EC wrote and revised this paper, MO and EC provided suggestions for the revision and framework of this paper, and AV and MO gave some ideas of this paper.

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