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Could Globalization and Renewable Energy Contribute to a Decarbonized Economy in the European Union?

Olimpia Neagu [1,*], Andrei Marius Anghelina [2], Mircea Constantin Teodoru [2], Marius Boiță [2] and Katalin Gabriela David [2]

1 "Vasile Goldiș" Western University of Arad, Romania; University of Oradea-Doctoral School in Economic Sciences, Romania; Academy of Romanian Scientists, Bucharest, Romania; neagu.olimpia@uvvg.ro
2 "Vasile Goldiș" Western University of Arad, Romania; anghelina.andrei@uvvg.ro; teodoru@europe.com; bmarius1963@yahoo.com; dvd_gbr@yahoo.com
* Correspondence: neagu.olimpia@uvvg.ro

Abstract: The study investigates the impact of globalization, renewable energy consumption and economic growth on CO2 emissions in 26 European Union (EU) countries for the period 1990-2020. The second-generation panel unit root tests are applied, the Westerlund cointegration test is used, and panel Fully Modified Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) techniques are employed to estimate the long-term relationship between variables. The causality relationship among variables under investigation is identified by the heterogeneous Dumitrescu-Hurlin causality test. It is found that globalization and renewable energy consumption contributed to the carbon emissions mitigation, while economic growth induced their increase. The results are robust when control variables (i.e., financial development, foreign direct investment and urbanization) are added in the model. Foreign direct investment and urbanization are contributors to carbon emissions increase whereas financial development induce their decrease. The effect of variables under consideration on carbon emissions is differentiated by the economic development and institutional quality level. Unidirectional causalities relationships were identified from globalization to carbon emissions and from carbon emissions to foreign direct investment and bidirectional relationships between economic growth, renewable energy consumption, financial development and carbon emissions. Policy implications of the findings are also discussed.

Keywords: globalization; renewable energy consumption; carbon emissions; European policies

1. Introduction

The process of globalization links countries and nations economically, financially and politically, impacting economies, political systems, environment, culture and prosperity around the world. In spite of recent opinion of experts related to the phenomenon of "de-globalization", [1–3]) empirical research provide evidence in support of a sound foundation of globalization [4], pp. 13–24, and also of that "*world economy will need more globalization*" [5]. De-globalization or a "new world order" is a newly introduced topic in political discourse and also a concern of scholars. The world is experiencing this shift due to the pandemic, the Russia's war in Ukraine, disruptions of global supply chains, the China-US trade tensions, higher global risks, decoupling economies, the rise of Indian population. All these appear to be threats to globalization, and also seriously alter the geopolitical landscape. Some voices are arguing that Covid-19 pandemic has slowed globalization, based on the diminished values of KOF globalization index in 2020. The decrease is registered mainly in high income countries, while in low and middle-income countries the value of KOF index remained unchanged. European countries remain highly globalized due to their free trade agreements and strong political efforts dedicated to economic integration [6].

In all countries, environmental pollution occurs due to factors as: economic growth, globalization, industrialization, investment or urbanization. All these factors require an increasing energy demand that cause more air pollution mainly consisting of carbon emissions, which represents around 79,04% of greenhouse gas emissions in the European Union (EU) in 2020 (computation based on World Development Indicators [7,8]). A possible solution for alleviating carbon emissions is to diversify the structure of the energy consumption mix by extending the share of energy from renewable sources and other forms of non-polluting energy. Larger share of renewable energy in the consumption mix would conduct to the decarbonized economy. European Union assumed an ambitious target for 2050, climate-neutrality (no net emissions of greenhouse gas), and also to raise the share of renewable energy to 45% by 2030 [9]. Member States are engaged in reforms implementing climate policies and green transition towards the goals of the European Green Deal [10] the long-term EU's strategy for a sustainable future.

In this context, studies on influence of globalization and renewable energy on environment could provide pertinent inputs for designing the EU energy policies.

In spite of a relatively rich literature on the impact of globalisation and renewable energy consumption on carbon emissions, only a few studies assess the impact of these variables along with financial development, urbanisation, foreign direct investment on carbon emissions in the European Union countries. As examples of studies we can nominate: Addai et al. [11] assessed the link between decarbonisation technology, economic globalisation, economic growth and energy consumption in the case of the German economy; Vatamanu and Zugravu [12] analysed the impact of financial development, institutional quality, renewable energy on carbon emissions in the EU countries; Ali et al. [13] investigated the relationship between carbon dioxide intensity of GDP and environmental degradation in Southern European countries; Horobeț et al. [14] evaluated the financial development-environmental quality nexus in the European Union; Horobeț et al. [15] linked the inward foreign direct investment to carbon emission in 24 European Union countries; Destek [16] studied how globalisation and environment are correlated in Central and Eastern European (CEE) countries; Rahman et al. [17] revealed the nexus between financial development, globalization and environmental degradation in Central and Eastern European countries; Ayeche et al. [18] highlighted the relationship between economic growth, financial development, trade openness and carbon emissions for 40 European countries; Al-Mulali et al. [19]estimated the influence of renewable electricity production, economic growth, trade openness, financial development and urbanisation on carbon emissions in 23 selected EU countries; Sadorski [20] explored the nexus financial development - energy consumption in Central and Eastern European frontier economies. None of them treat the whole set of proposed economic variables in their link with carbon emission.

The present research aims to overcome this gap in existing literature and provide an overview of the nexus between globalization, renewable energy and carbon emission at the EU level, alongside with other pollution determinants (financial development, foreign direct investment and urbanization), taken into consideration that European countries are highly globalized and high renewable energy producers in the world and aim to be climate-neutral in 2050.

The contributions of the present study to the existing knowledge are consisting of: (1) employing heterogeneous panel estimation techniques that allow for cross-section dependences to model the impact of globalization and renewable energy on carbon emissions in the EU countries; (2)giving an overall image of the impact of globalization and renewable energy use in the EU and adding a fresh overview to the limited existing evidence on the EU territory; (3) highlighting the role of economic development level and institutional quality in mitigating the carbon emissions; (4) the findings are useful for researchers, academics, governments and policymakers, providing support for environmental and energy policies design at the EU level (i.e., implementation of the European Green Deal).

The paper is structured as follows: Section 2 discusses the current relevant literature; Section 3 describes data and methodology; Section 4 presents the main findings; Section 5 provides the discussion of results; and Section 6 includes conclusions and policy implications.

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2. Literature Review

This section discusses recent studies regarding the impact of globalization, renewable energy, economic growth on pollution, as well as other factors such as: financial development, foreign direct investment and urbanization.

2.1. Globalisation and pollution

An impressive recent literature is devoted to exploring the link between globalization and environment. Studies regarding this link diverging results, a part of them revealing a positive association and another, a negative one.

Shabaz et al. [21] found that globalization contributed to the decrease of CO2 emissions in China in the period of 1970 to 2012. Similar results are reported by Patel and Mehta [22] for India and by Islam et al. [23] for Bangladesh. Lv and Xu [24] reveal that an increase of 1% of economic globalization reduces CO2 emissions by -0.11% in 15 emerging countries over the period 1970-2012 by using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model. You and Lv [25] analyzed the spatial effect of globalization on CO2 emissions in a panel of 83 countries for the period of 1985 to 2013. They found that the effect of globalization on CO2 emissions is significantly negative. Zaidi et al. [26] concluded that globalization significantly reduced carbon emissions in the APEC countries using the Continuously Updated Bias Corrected (CUP-BC) and Continuously Updated Fully-Modified (CUP-FM) methods for data from 1990 to 2016. Globalisation had a reducing effect on carbon emissions in Central and Eastern European countries in the period of 1980 to 2016, according to the results of Rahman et al. [17], based on Dynamic Seemingly Unrelated Regression (DSUR) method. It is identified a reducing effect of globalization on CO2 emissions in MENA countries during 1970 to 2015, by using Feasible Generalized Least Squares (FGLS) approach [27]. Koengkan et al. [28] explored the impact of globalization on CO2 emission in 18 Latin American and Caribbean economies with data for the period of 1990 -2014 in a panel non-linear autoregressive distributed lag (PNARDL) and conclude that globalization (overall index and its components) exerts an adverse impact on carbon emissions. Yang et al. [29] revealed that globalization reduce carbon emissions in a global sample of 97 countries during 1990-2016, within a Generalized Method of Moments (GMM) approach. Aladejare [30] reports that globalization reduced environmental degradation in the five richest African economies from 1990 to 2019, by using four estimation techniques: fixed and random effect, feasible generalized lest squares and augmented mean group. Ansari et al. [31] conclude that globalization had a reducing effect on carbon emissions in the case of ten carbon emitters of developing countries over the period 1980-2018 using a Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) model. This is in line with the results of Rahman and Alam [32] for Asian countries. In a global panel of 73 developing countries, Jahanger et al. [33] found that globalization has an adverse impact on carbon emissions using Two-Stage Least Squares (2SLS) and panel threshold methods.

A group of studies took into consideration different dimensions of globalization. For example, *de facto* economic globalization increased environmental degradation in 23 African countries from 1999 to 2017 while *de jure* economic and political globalization improved the environment [34]. Leal and Marques [35] found that overall, globalization increased environmental degradation, but the *de jure* measure has greater influence in high-globalized countries, while *de facto* measure in the low-globalized ones in the case of European Union countries. Destek [16] found that the different dimensions of globalization have different impacts on carbon emissions. His study on Central and Eastern European (CEE) countries for 1995 to 2016 revealed that overall, economic and social globalization increases environmental pollution, whereas political globalization can reduce the carbon emissions. Jahanger [36] found that political globalization can reduce environmental degradation, whereas economic, social and overall globalization increases the carbon emissions in 78 developing countries from 1990 to 2016. Economic globalization improves environmental quality in Sub-Saharan Africa [37] and Germany [11]. Social globalization can increase carbon emission in developing countries [38]. The findings of Jaganger et al. [38] on 78 developing economies over the period from 1990 to 2016, based on a Two-Stage Least Squares Generalized Method of Moments

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(2SLS-GMM) method show that political globalization reduces it, while economic globalization causes its increase. In their study on 170 countries around the world from 1990 to 2018, Muhammad and Khan [39] conclude that social globalization has boosted the carbon emissions, whereas economic globalization and political globalization reduced them. Awad and Mallek [40] found that economic globalization directly harms the environment in 44 countries from Sub-Saharan Africa between 2003 and 2020 and also, that information and communication technologies could reduce this impact.

The level of economic development is also a differentiating factor in the analysis of globalization on environment. Globalisation plays a significant role in the lower-income countries, by mitigating carbon emissions, while it increases carbon emissions in the high-, low-, upper, and middle-income countries [41]. According to the findings of Leal et al. [42], globalization has caused 0.2% and 0.52% increase of environmental degradation in developing economies and reduction of 0.88% and, 0.85%, in developed ones.

The degree of globalization is also important in the relationship between globalization, income and carbon emissions. Chiu and Zang [43] found that more globalization has a negative effect on carbon emissions across 95 countries and in more globalized countries this effect is stronger. After globalization reaches a threshold, it has a negative effect on carbon emission in both, high- and low-income countries, and this effect is larger in the high-income countries. Rehman et al. [44] report that only negative shock to the globalization index influence carbon emission and when globalization declines, the carbon emissions level tend to increase in a global sample of countries, for 1985-2020. Similarly, negative economic growth shocks negatively influence the carbon emission levels. Ivanovski and Hailemariam [45] revealed that globalization has a positive effect on CO2 emissions in a panel of 21 OECD economies in the period of 1970 to 2014 until 2000. After 2000, it switched to a negative impact.

Another group of studies reports a positive association between globalization and carbon emission. For example, an enhancing effect of globalization on emissions is found in Japan [46], India [47], China [48–50], Argentina [51], and Australia [52].

Globalization increased carbon emissions in 25 developed countries, according to the findings of Shahbaz et al. [53], based on the analysis of 1970-2014 data using Common Correlated Effect Mean Group (CCEMG). The same results for developed countries are reported by Huo et al. (2022) [54], based on the Wavelet Coherence and Quantile Regression approaches. Economic globalization increased carbon emissions in the long term in OECD countries, as it is resulted by running a Pool Mean Group (PMG) estimation technique for 1990-2015 data [55]. Similar findings were described for NAFTA countries using the Driscoll-Kray estimator [56] and South-Asian economies, based on a Fully Modified Least Squares (FMOLS) approach [57], Feasible Generalized Least Squares (FGLS) technique [58], and FMOLS estimator [59]. Similar findings are reported for South Asian Association for Regional Cooperation (SAARC) countries over the period 1990-2018, using the Pool Mean Group (PMG) approach [60], as well as in G20 countries in the period from 2005 to 2018, based on the Cross-Sectional Augmented Autoregressive Distributed lag (CS-ARDL) technique [61].

2.2. Renewable energy consumption and carbon emissions

Renewable energy use negatively affects CO2 emissions [32,62–66]). Alola and Joshua [41] revealed that renewable energy use improves environmental quality by reducing the carbon emission only in the short run in high-, low- and upper-middle-income countries. Renewable energy consumption reduced carbon emissions in 18 Latin American and Caribbean economies [28]. Adebayo et al. [67] report similar findings in the Brazilian economy for the period of 1990 and 2018. Renewable energy consumption reduced carbon emissions generated by energy production in Argentina based on data from 1971-2016 [51]. Renewable energy decreased CO2 emissions in the Nordic countries (1980-2020) [68]. Ansari et al. [31] found that renewable energy has a negative and significant impact on carbon emissions in developing countries, in line with the results reported by Kwakwa [69] for 32 African countries and Cao et al. [70] for 37 OECD countries.

Renewable energy had a negative impact on carbon emissions in G20 countries in the period from 2005 to 2018 [61]. Also, Sheraz et al. [71] found that renewable energy reduced carbon emissions in 64 Belt and Road Initiative countries. Amin and Song [72] report similar findings for South Asia and Sun et al. [73] for MENA countries. In a study on 130 countries from 1992 to 2019, Li et al. [74] concluded that there is a negative relationship between renewable energy use and carbon emissions: when renewable energy consumption increases, the negative effect on carbon emissions become more significant. Furthermore, the effect is stronger in poor countries than in rich countries.

2.3. Economic growth and carbon emissions

Economic growth is positively associated with carbon emissions increase [11,13,32,52,54,65–67,73,75–81]. GDP per capita and urbanization growth determined environmental degradation in Asian Association for Regional Cooperation (SAARC) countries [60], also in Bangladesh [23]. Economic growth caused increase of carbon emissions in APEC economies over the period 2000-2019 [82]. Contrary to these results, recent studies reveal that economic development is negatively linked with carbon emissions globally, in Europe, Africa and Asia [83], and also in Singapore [84]. Developed and developing countries are experiencing different paths on the economic development and environmental quality. Economic growth and financial development mitigate carbon emissions in high-income economies but have an opposite effect in low- and middle-income economies [85].

2.4. Other variables with imoact on carbon emissions

Financial development

The relevant literature regarding the nexus between financial development and carbon emissions provide mixed results. A part of studies reports a positive correlation, another part, a negative one, and some of them reveal dual effects of financial development on carbon emissions.

Financial development is seen as a determinant of carbon emissions [75,76,86]. Zaidi et al. [26] concluded that financial development significantly reduced carbon emissions in the APEC countries (1990-2016). Financial development reduced CO_2 emissions in MENA countries during 1970 to 2015 [27]. Kirikkaleli and Adebayo [65] found that global financial development has a significant positive effect on environmental sustainability by decreasing the carbon emissions. Guo and Hu [87] report similar results in the case of Chinese economy. Sheraz et al. [79] report that financial development decreased carbon emission in G20 countries from 1986 to 2018.

Financial development decrease CO_2 emissions in the short and long term in the Nordic countries (1980-2020), according to Wu et al. [68]. Hung [88] found that financial development plays an important role in environmental degradation and a decrease of CO_2 emissions can predict a negative financial development in Vietnam. Ahmad et al. [89] concluded that financial development can restrain the increase of carbon emissions through human capital. Khan and Ozturk [90] provide evidence in support of pollution inhibiting role of financial development in a sample of 88 developing countries during 2000-2014.

A significant positive impact of financial development on carbon emissions was identified in Nigeria [77], in G8 and D8 countries [91], in South Asian Association for Regional Cooperation (SAARC) countries [60], in 64 Belt and Road Initiative (BRI) [71], and in the EU countries [14]. Acheampong et al. [92] proved that financial development reduced carbon emissions over the period of 1980-2015 in developed countries and it has an opposite effect in developing countries. Similarly, Jiang and Ma [93] found that in developing economies financial development has a positive impact on carbon emissions and no obvious influence in developed economies.

Liu et al. [94] showed that financial development has dual effects on carbon emissions in the BRI countries for the period of 1997-2019, one restraining and one rebounding. The restraining effect decreases in time, leading to a blocking point. Financial development led to decrease carbon emissions in eighteen APEC countries in 2000-2019, according to the results of Hasni et al. [95]. The same result is reported by Patel and Mehta [22] in the case of Indian economy.

Contrary to these findings, Rahman et al. [17] found no significant link between financial development and carbon emissions for Central and Eastern European countries in the period of 1980-2016, similarly to Ayeche et al. [18] for 40 European countries over the period 1985 to 2014.

Urbanization

Urbanization was revealed as stimulating factor of carbon emission in Argentina [61] and Bangladesh [23], in South Asian Association for Regional Cooperation (SAARC) countries [60], in MENA region [73], and Singapore [84]. Urbanization increased CO2 emissions in the short and long run in South Asia [72]. Differently from these conclusions, Aladejare [30] reports a positive effect of urbanization on environmental sustainability in the 5 richest African countries, in a similar way of Lv and Xu [96] for middle-income countries and Kwakwa et al. [97] for Ghana.

Foreign direct investment

Foreign direct investment (FDI) caused more pollution in MENA countries during 1970 to 2015 [27] whereas other studies revealed that foreign direct investment has a negative effect on carbon emissions [12,98,99]. Similarly, Horobet et al. [15] concluded that inward FDI positively impacted the reduction of carbon emissions in 24 EU countries, as did Jahanger et al. [33] for 73 developing economies. Abdul-Mumuni et al. [100] revealed an asymmetrical link between FDI and carbon emission in the long run: a positive shock of FDI will lead to an increase of carbon emissions, while a negative shock will induce a decrease of them. FDI had a positive impact on carbon emissions in Ghana for 1971-2018 [92] and Italy for the period 1971-2019 [81]. The study developed by Wang et al. [101] for 67 countries shows that the FDI has a positive impact on carbon emissions for countries with GDP per capita lower than 541.87 USD, and a negative impact when GDP per capita exceeds this level.

We can notice from the above lines the scarcity of studies on European area, and also, that European countries are less investigated regarding the nexus between globalization, renewable energy and carbon emissions in the presence of other pollution stimulating factors such as: financial development, urbanization and foreign direct investment. Our study intends to cover this gap by enlarging the literature focused on globalization and environment in the European Union, given the need for effective energy policies to overcome the climate change and environmental degradation issues, and conducing to ambitious goal of decarbonized economy by 2050.

3. Data and Methodology

3.1. Data

Data for the study cover the period of 1990 to 2020 for 26 European Union countries (Austria, Belgium, Bulgaria, Croatia, Czech Republic, Cyprus, Denmark, Estonia, Germany, Greece, Hungary, Finland, France, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Spain, Slovakia, Slovenia, Sweden.

The study was motivated by previous relevant theoretical foundation and empirical analyses, the selected variables under consideration being consistent with them. Table 1 displays the study's variables, measurement and their source.

The dependent variable is expressed by carbon emissions per capita (in metric tons), as a proxy for air pollution, meaning emissions stemming from fuels (fossil, liquid and gas), consistent with Soaib et al. [91], Hafeez et al. [102], Gyamfi et al. [103], Muhammad and Khan [104], Muhammad et al. [105], Sun et al. [106], Zhuo and Qamruzzaman [107], and Jiang et al. [108].

The independent variables are: globalization, gross domestic product per capita, renewable energy consumption as variables of interest, and financial development, foreign direct investment and urbanization, as control variables.

The KOF index of globalization, as a measure of globalization, was introduced by Dreher (2003) at the KOF Swiss Economic Institute and it has been updated in 2008, 2018 and 2019 [109–112]. The study uses the overall index of globalization (including all dimensions: economic, social and political) [6]. This variable was employed in previous studies focused on the link between globalization and pollution [23,45,46,59,60,70,104].

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Gross Domestic Product (GDP) per capita is the proxy for economic growth in our study. GDP per capita based on purchasing power parity (PPP) is the economic output (in international dollars using purchasing power parity rates) divided to population and it reflects the state of development of the country. The nature of its relation with carbon emissions (negative or positive) depends on the share of energy from renewable sources in the energy consumption mix required by the economic development.

Renewable energy consumption is expressed by the share of energy from renewable sources in the total final energy consumption. We expect a negative relationship between carbon emissions and renewable energy use (i.e., renewable energy has a reducing effect on environmental degradation). This metric for renewable energy consumption was also used by: Rahman and Alam [32]; Wang et al. [55]; Sadiq et al. [59], Kirikkaleli and Adebayo [65]; Kwakwa [72], Amin and Song [73], and Li et al. [74].

Financial development is a multidimensional process influencing the whole society, comprising evolving financial institutions and markets. Our study uses the financial development indicator developed by International Monetary Fund (IMF) [113,114]. The IMF index is defined by a combination of characteristics of financial institution (access and efficiency) and financial markets (size and liquidity) [114]. Several studies analyzing the impact of financial development on environmental quality work with this index [12,14,77,89,92,95,115].

As a variable impacting pollution in the EU countries, foreign direct investment is measured by the net inflow of foreign investment as percentage of GDP. This measure is present in the empirical analyses of factors influencing carbon emissions [15,81,100,116,117].

Urbanization, as potential factor for CO2 emission increase, is measured by % of urban population in the total population. This indicator has been used in related studies on the link between globalization and carbon emissions, such as: Islam et al. [23], Aladejare [30], Muhammad and Khan [39], Murshed et al. [51], Azam et al. [60], Kwakwa et al. [69] Amin and Song [72], and Sun et al. [73].

Table 1. Variables: symbol, measurement, and source.

Symbol	Variable	Measurement	Source
		Dependent variable	
CO2	Carbon dioxide emissions	Metric tons per capita	World Bank [118]
		Variables of interest	
GDPpc	Gross Domestic Product per capita	Gross Domestic Product per capita on Purchasing Power parity (PPP) constant international 2017 international USD)	World Bank [119]
KOF	Globalisation	Overall Globalisation Index Overall	KOF Swiss Economic Institute [6]
REC	Renewable Energy consumption	Share of renewable energy in the total final consumption (%)	World Bank [120]
		Control variables	
FinDev	Financial Development	Financial Development Index: an aggregate of Financial Institutions Indez (Banking sector) and Financial Markets Index (market capitalisation)	International Monetary Fund (IMF) [114]
FDI	Foreign Direct Investment	Foreign Direct Investment Inflows, as % of GDP	World Bank [121]
URB	Urbanisation	Share of urban population in the total population (%)	World Bank [122]

Table 2 provides the summary of the descriptive statistics of variables. All variables are in ln. Over the period (1990-2020) we note that overall standard deviations are generally is low. The highest value is recorded by *lnGDP* per capita (10.34840), while the minimum value is registered for *lnFDI* (-10.61131).

Table 2. Descriptive statistics of variables.

	lnCO2	*lnFinDev*	*lnFDI*	*lnGDPpc*	*lnKOF*	*lnRENE*	*lnURB*
Mean	1.984917	-0.804342	0.781727	10.34840	4.334920	2.362099	4.239015
Median	1.989818	-0.692153	0.879344	10.40894	4.380615	2.450573	4.230368
Maximum	3.413184	-0.104631	4.313947	11.70063	4.509831	3.968025	4.585386
Minimum	1.074004	-4.806411	-10.61131	9.169518	3.721731	-1.094043	3.869429
Std. Dev.	0.418699	0.539448	1.338030	0.504522	0.148314	0.943458	0.168917
Observations	806	806	806	806	806	806	806

Source: authors' own computation

3.2. Methodology and Econometric Strategy

3.2.1. Methodology

Following previous research on the impact of globalization and renewable energy on carbon emissions [38,73] mathematical representation of our model is as follows:

$$lnCO2_{i,t} = \alpha + \beta_1 \cdot lnGDP_{pc\,i,t} + \beta_2 \cdot lnKOF_{i,t} + \beta_3 \cdot lnREC_{i,t} + \beta_4 \cdot CV_{i,t} + \varepsilon_{i,t} \quad (1)$$

where: i denotes the country and t the time, respectively; CO2 represents the carbon emissions per capita, *GDPpc* is Gross Domestic Product per capita, *KOF* denotes the KOF globalization index (overall), *REC* stands for the renewable energy consumption (as % of the total final consumption); *CV* expresses a set of control variables: Financial Development (*FinDev*), Foreign Direct Investment (*FDI*) and Urbanization (*URB*); β_1, β_2, β_3, β_4 are coefficients to be estimated and $\varepsilon_{i,t}$ is the stochastic error term.

The Equation (1) is estimated in *ln* in order to minimize the variations of variables under consideration. The control variables will be successively added, one by one, thus generating additional models.

3.2.2. Econometric Strategy

The methodology consists of the following steps: (1) cross-sectional dependence test; (2) stationarity check of considered variables; (3) cointegration test; (4) estimation of long-run coefficients of FMOLS and DOLS models; (5) robustness check of results; (6) testing the causality between variables.

3.2.2.1. Cross-sectional Dependence

Usually, cross-sectional dependence in the data series can be detected due to unobserved mutual factors, spillover effect or common shock. If the cross-sectional dependence is detected traditional unit root tests may provide bias outcomes. For reliable results, we use Breusch-Pagan LM [123], Pesaran Scaled LM test, Bias-corrected scaled LM and Pesaran CD tests [124]. The null hypothesis of cross-sectional dependence is accepted in the case of p value is lower than 0.01. The statistic of Pesaran CD is given by the equation:

$$D = \sqrt{\frac{2}{N(N-1)}} * \left(\sum_{i=1}^{N-1} \sum_{j=1+1}^{N} T_{ij} p_{ij} \rightarrow N(0.1) \right) \quad (2)$$

where: p_{ij} stands for the correlation coefficients of residuals, N denotes the number of countries and T the time.

3.2.2.2. Stationarity of Variables

Before applying the cointegration test and estimation techniques, we intent to identify the integrated properties of variables under consideration. We propose to use second-generation of panel unit root tests, that are based on the heterogeneity assumption, thus avoiding the short-comings of cross-sectional dependence of the first-generation unit root tests. We apply two types of second-generation panel unit root tests, namely those proposed by Pesaran [125]: Cross-Sectional Augmented Dickey-Fuller (PES-CADF) and Cross-Sectional Im, Pesaran and Shin (CIPS).

The CADF test consists of standard Dickey-Fuller (DF) regressions that are augmented with the cross-sectional average of lagged series at their levels and the first difference series of the *i*-th cross-section in the panel are run, as follows:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \delta_i y_{t-1} + \sum_{j=0}^{k} \delta_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{k} \Delta y_{i,t-j} + \varepsilon_{it} \tag{3}$$

where: $y_{t-1} = \frac{1}{N}\sum_{i=1}^{N} y_{i,t-1}$; $\Delta y_t = \sum_{i=1}^{N} y_{it}$; α_i is a constant; k specifies the lag; t_i (N,T) is the t-statistic of the estimated ρ_i.

CIPS is computed as the mean of individual CADF statistics for individual cross-sections:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \tag{4}$$

where: t_i (N,T) denotes the CADF statistics for the *i*-th cross section in the CADF regression.

For both tests, the null hypothesis of homogeneous unit root states that "all sections in the panel are nonstationary", while under the alternative hypothesis, "at least, one individual section is stationary". Both tests are largely used in the literature regarding the impact of various economic, financial or energy variables, such as: globalization, economic growth, financial development, renewable/non-renewable energy on carbon emissions or environmental quality [115,126–145].

3.2.2.3. Cointegration Test

In the presence of cross-sectional dependence, the error correction-based panel cointegration test, proposed by Westerlund [146] provide robust results [147]. The test is currently used in the literature related to influence of economic and energy variables on pollution [13,30,31,40,55,61,73,83,89,116,148].

Within this test, the null hypothesis of no cointegration is based on checking the presence of a unit root of residuals. The alternative hypothesis under this test states that some panels are cointegrated, based on computing the variance-ratio (VR) statistic. The test is based on two assumptions regarding the presence of cointegration of variables: (1) in *some of the panels*, and (2) in *all the panels*. Based on the p-value of the VR-statistic the rejection or acceptance of the null hypothesis of no cointegration is made. If the p-value is under the chosen significance level, the null hypothesis is rejected in the favor of the alternative, that at least, *some panels or all panels* are cointegrated.

3.2.2.4. Panel Model Estimation

We estimate the equation (1) by using the panel models developed by Pedroni [149,150] namely, Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS).

Within the panel FMOLS model the following regression is used:

$$y_{it} = \alpha_{it} + \delta_{it} t + \beta x_{it} + \mu_{it} \tag{5}$$

$$x_{it} = x_{it-1} + e_i \tag{6}$$

where: y_{it} represents the dependent variable and x_{it} the independent variable, α_{it} denotes the constant effects, β stands for the long-term cointegration coefficient that will be estimated under the assumption of no panel cross-sectional dependence.

The panel FMOLS estimator for the i-*th* cross-section is given by:

$$\hat{\beta}^*_{FM} = n^{-1}\sum_{i=1}^{n} \hat{\beta}^*_{FM,i} \tag{7}$$

The T-statistic for the panel cointegration coefficient is computed as bellow:

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$$t^{*}_{\hat{\beta}^{*}_{FM}} = n^{-1}\sum_{i=1}^{n} t_{\hat{\beta}^{*}_{FM,i}} \quad (8)$$

The DOLS estimator is the result of the following regression estimation:

$$y_{it} = \alpha_i + \beta_i x_{it} + \sum_{k=-K_i}^{K_i} \gamma_{it}\Delta x_{it-K} + \varepsilon_{it} \quad (9)$$

The above equation is estimated for each panel cross-section. Further, the cointegration coefficient of the overall panel is calculated as the average of the DOLS coefficients of each section.

The panel DOLS estimator is given by the formula:

$$\hat{\beta}^{*}_{D} = n^{-1}\sum_{i=1}^{n} \hat{\beta}^{*}_{D,i} \quad (10)$$

The t-statistic for the panel cointegration coefficient is computed as:

$$t^{*}_{\hat{\beta}^{*}_{D}} = n^{-1}\sum_{i=1}^{n} t_{\hat{\beta}^{*}_{D,i}} \quad (11)$$

The panel FMOLS and DOLS approach was also used by Sahoo and Sethi [151] for analysing the impact of renewable and non-renewable energy, globalisation, natural resources and human capital on environmental quality in developing countries, as well as by Kirikkaleli and Adebayo [65] for a global sample of countries. The FMOLS model was employed by Al-Mulali et al. [19] to explore the effect of economic growth, trade openness, renewable energy, financial development and urbanisation on pollution in selected European countries, as well as by Wang et al. [55]to examine the linkage between CO2 emissions human development, financial development and globalisation in OECD countries, and also by Wang et al. [140] to analyse the impact of FDI on environmental quality in 67 countries.

3.2.2.5. Robustness check of results

The robustness check of our results will be performed in two parts: (1) adding the control variables to the variables of interest in the equation (1); (2) dividing the panel of 26 EU countries into two subpanels according to two criteria: economic development and institutional quality level.

The level of economic development creates the capacity of a country to address problems related to mitigate pollution, openness for trade and foreign investment, financial development or diversifying the energy consumption mix. Based on this criterion, we divided the 26 EU countries in two subpanels: developed and developing countries, meaning a set of 15 Western developed countries (old Member States: Austria, Belgium, Cyprus, Denmark, Germany, Finland, France, Greece, Italy, Ireland, Luxembourg, Netherlands, Spain, Portugal and Sweden) and 11 countries from Central and Eastern Europe (Czech Republic, Poland, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Hungary, Bulgaria, Romania and Croatia).

As institutions shape economic, energy and environmental policies, it is crucial to incorporate institutional variables when analysing the nexus between renewable energy, CO2 emissions and economic growth to prevent variable omission bias. Institutional quality entails good governance, implication of law, quality of bureaucracy or corruption. The role of institutions quality in mitigating pollution is revealed in several papers as a moderating factor of the influence of various pollution determinants. As Kim et al. [152] highlighted, high institutional quality decreases energy use and carbon emissions. Ahmad et al. [89] concluded that institutional quality reduces the ecological impact of financial development in emerging countries. Simionescu et al. [153] found that institutional quality (rule of law, regulatory quality and control of corruption contributed to the environmental quality in the long run as well as the renewable energy consumption in the period of 2002-2008, by reducing the level of GHG emissions in the Central and Eastern European countries. Sheraz et al. [71] pointed out that institutional quality is related to carbon emissions, a low level (bad governance, corruption, quality of bureaucracy) being associated with environmental degradation. Corruption as

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a dimension of institutional quality, increased carbon emissions in Asian countries [32]. Institutional quality and governance positively influence renewable energy consumption [12]. Kwakwa [69] reports the same in the case of African countries based on data covering 2002-2021. Carbon emissions are substantially reduced by corruption control, regulatory quality and the rule of law [154]. Institutional quality reduced CO2 emissions in G-7 countries [155] and 45 sub-Saharan African countries [156]. Khan and Rana [157] revealed that better economic institutions helped in reducing pollution emissions in 41 Asian economies from 1996 to 2015 while institutional quality can moderate the negative impact of financial development on carbon emissions [158] in South Asian Economies. Islam et al. [159] found that institutional quality stimulates renewable energy consumption in Bangladesh. Jiang et al. [108] revealed also that improvement in institutional quality curb carbon emission in the panel of 57 Belt and Road (B&R) countries over the period 1995 to 2018, in line with the results of Jahanger et al. [33] for 73 developing countries from Asia, Africa and Latin America.

In order to differentiate the effect of globalisation and renewable energy consumption on carbon emissions in the EU economies, based on institutional quality of countries, we used indicators from Worldwide Governance Indicators database [160]. It includes six components of governance: voice and accountability, political stability and lack of violence, rule of law, government effectiveness, regulatory quality and control of corruption [161]. We computed the mean of these governance indicators for the EU countries in the period of 1996-2020. We split the panel of EU 26 countries into two parts: 13 countries with a mean above 1 (high level of institutional quality) (Austria, Belgium, Cyprus, Germany, Denmark, Finland, France, Ireland, Luxembourg, Netherlands, Estonia, Portugal and Sweden) and 13 countries with a mean under 1 (low level of institutional quality (Greece, Italy, Spain, Bulgaria, Croatia, Czech Republic, Latvia, Lithuania, Poland, Hungary, Romania, Slovakia and Slovenia).

This splitting is motivated by the fact that pollution, globalization, economic growth, energy mix (i.e., share of energy from renewable sources), financial development, foreign direct investment are subjects of national policies, designed and implemented by institutions. Institutional quality is important to adopt renewable energy, to stimulate green investment, to effectiveness of environmental rules, can stimulate or impede globalisation, financial development or the level of urbanisation.

3.2.2.6. Panel Causality test

In order to identify the direction of causal relationship between the variables will be used the Dumitrescu and Hurlin [162] test. This is appropriate for heterogeneous panel data and widely used in analyses of the impact of economy on pollution [18,21,30,55,59,60,71,73,76,115,155,163].

Under the null hypothesis of no causality running from x to y, we have:

H0: $\beta_i = 0$ for $\forall i = 1,\dots,n$; $\beta_i = (\beta_i^{(1)}, \beta_i^{(2)},\dots,\beta_i^{(k)})$

The alternative hypothesis assumes that there are $n_1 < n$ individual processes with no causal relationship

from x to y:

H1: $\beta_i = 0$ for $\forall i = 1,\dots,n_1$

$\beta_i \neq 0$ for $\forall i = n_1, n_1+1, n_1+2,\dots,n$

where: $0 \leq \frac{n_1}{n} < 1$. When $n_1 = n$, no causality is identified for any section in the panel. When $n_1 = 0$, causality is identified for all sections in the panel. When $n_1 > 0$, the causality relationship is heterogeneous. The Dumitrescu-Hurlin test first computes the individual Wald statistics, to identify

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the causality relationship in each section, and then computes the overall Wald statistic as their average:

$$W_{n,T} = \frac{1}{n}\sum_{i=1}^{n} W_{i,T} \quad (12)$$

The null hypothesis of non-causality states that each individual Wald statistic will converge to a chi-squared distribution:

$$W_{i,T} \xrightarrow{d} \chi^2(K), \forall i = 1,\ldots,n \quad (13)$$

K = freedom degrees

When T→ ∞ , then the individual Wald statistics are identically distributed, assuming that individual residuals are independently distributed across sections.

When $T < n$, the Z-statistic is computed as bellow:

$$Z_{n,T} = \sqrt{\frac{n}{2K}}\left(W_{n,T} - k\right) \to n(0,1) \quad (14)$$

When the value of Z-statistic is above the critical value of a given risk level, the null hypothesis of homogeneous non causality is rejected.

4. Main findings

4.1. Cross-sectional dependence test

The results displayed in the Table 3 suggest that the null hypothesis of cross-sectional independence is rejected for the 1% significance level for all the variables under consideration, indicating the presence of cross-sectional dependence among variables.

As a consequence, we use the second-generation unit root tests for the levels and the first-order differences of variables, namely CIPS and CADF.

Table 3. Results of the cross-sectional dependence test.

	lnCO2	*lnGDPpc*	*lnKOF*	*lnREC*	*lnFinDev*	*lnFDI*	*lnURB*
Breusch-Pagan LM	3417.781*	8177.36*	7100.18*	5708.25*	5573.02*	1026.37*	6614.57*
Pesaran Scaled LM	121.308*	305.64*	265.74*	211.14*	205.84*	27.51*	246.69*
Bias corrected Scaled LM	120.86*	305.19*	265.29*	210.70*	205.39*	27.06*	246.24*
Pesaran CD	43.66*	89.30*	80.66*	72.37*	69.99*	21.22*	16.98*

Note: *p<0.01. Source: authors' computation based on EViews 12.0 software.

4.2. Stationarity test

We notice from the Table 4 that *lnREC, lnFinDev, lnFDI* are stationary at their levels and also at their first difference, while *lnCO2, lnGDPpc, lnKOF and lnURB* are stationary only their first difference for minimum 5% statistical significance. Thus, we can conclude that all variables are integrated at their first order (I (1)).

Table 4. Stationarity test results.

Variable	PES-CADF test z (t-bar)		CIPS test CIPS statistic	
	constant	*constant and trend*	*constant*	*constant and trend*
lnCO2	-2.155**	-2.097	-2.238**	-2.409
ΔlnCO2	-3.657*	-3.971*	-4.711*	-5.127*
lnGDPpc	-2.142**	-2.492	-2.031*	-2.441*
ΔlnGDPpc	-3.200*	-3.220*	-3.922*	-3.916*
lnKOF	-2.011	-2.186	-2.456	-2.774

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ΔlnKOF	-3.395*	-3.848*	-4.996*	-5.391*
lnREC	-2.624*	-2.741*	-2.164**	-2.431**
ΔlnREC	-3.554*	-3.833*	-4.946*	-5.242*
lnFinDev	-2.966*	-3.277*	-2.971*	-3.390*
ΔlnFinDev	-4.584*	-4.565*	-5.402*	-5.524*
lnFDI	-3.285*	-3.535*	-4.735*	-5.022*
ΔlnFDI	-5.270*	-5.304*	-6.186*	-6.402*
lnURB	-1.536	-1.996	-0.865	-0.801
ΔlnURB	-2.158**	-2.305**	-2.028*	-2.305*

Note: *p<0.01; **p<0.05. Source: authors' computation based on Stata 15.1 software.

4.3. Cointegration test

The results of Westerlund cointegration test for the EU panel (Table 5) reveal the existence of a long-run relationship between the considered variables for 5% significance. The cointegration relationship is maintained when the control variables are added (rows 2-4 from Table 5).

Table 5. Westerlund cointegration test.

Variables	Assumptions:			
	" some panels are cointegrated"		*"all panels are cointegrated"*	
	statistic	p-value	statistic	p-value
LnCO2, LnGDPpc, lnKOF, lnREC	-2.751	0.0030	-1.804	0.0329
LnCO2, LnGDPpc, lnKOF, lnREC, lnFinDev,	-2.298	0.0108	-1.466	0.0500
LnCO2, LnGDPpc, lnKOF, lnREC, lnFDI	-1.8131	0.0349	-1.346	0.0500
LnCO2, LnGDPpc, lnKOF, lnREC, lnURB	-3.394	0.000	-1.910	0.0281

Source: authors' computation based on Stata 15 software..

Given the identified cointegration relationship between the considered variables, we further proceed to estimate the long-run coefficients of equation (1).

4.4. Long-run coefficients estimation

We ran the FMOLS and DOLS estimations for four models, by successively adding, one by one, the control variables (*lnFinDEv, lnFDI, lnURB*) to our interest variables (*lnGPDpc, lnKOF, lnREC*). The results are displayed in Table 6a.

Table 6a. Regression estimation -EU panel (26 countries) Dependent variable: lnCO2.

	Model 1		**Model 2**		**Model 3**		**Model 4**	
	FMOLS	**DOLS**	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**
Variables	**-coefficients-**							
lnGDPpc	0.5310*	0.5317*	0.5596*	0.5558*	0.5244*	0.5279*	0.5065*	0.4987*
lnKOF	-0.7078*	-0.7096*	-0.7821*	-0.7735*	-0.7023*	-0.7075*	-0.9162*	-0.9184*
LnREC	-0.1883*	-0.1870*	-0.1892*	-0.1879*	-0.1808*	-0.1823*	-0.1776*	-0.1753*
lnFinDev			-0.0377*	-0.0378*				
lnFDI					0.0323*	0.0244*		
lnURB							0.2674*	0.2878*
R-squared	0.4904	0.4848	0.4926	0.4870	0.4984	0.4908	0.5017	0.4975

Source: authors' computation based on EViews 12.0 software. Note: *p<0.01.

Economic growth induced the increase of carbon emissions, the coefficient of *lnGDPpc* being statistically significant for 1% significance threshold in all four models. Globalisation has a negative significant impact on carbon emissions alongside with renewable energy use (the value of Prob. for all coefficients is less than 0.01). Besides, financial development caused the reduction of carbon

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emissions, while foreign direct investment and urbanization led to the increase of carbon emissions (for a threshold statistical significance of 1%) (Table 6a).

4.5. Robustness Analysis

We conducted an additional analysis in order to check the robustness of our findings. This analysis has two components. The first one refers to adding three control variables: financial development index (*FinDev*), foreign direct investment (*FDI*) and urbanization (*URB*). The cointegration relationship is also validated when the control variables are added as it is shown in Table 5 (rows 3-4). In Table 6a–d, columns Model 2, Model 3 and Model 4, respectively include the estimation of regression parameters including these control variables. As we can notice, the correlation between the variables of interest (*GDPpc*, *KOF* and *REC*) and CO2 emissions is maintained. Economic growth induced an increase of CO2 emissions while globalization and renewable energy use caused their reduction in the panel of 26 countries. Financial development (*FinDev)* is found to be a reducing factor of carbon emissions, while urbanization and *FDI* contributed to their increase.

The second component of robustness analysis consisted of running the regression model within two types of sub-panels of the EU countries, based on the level of economic development, and the institutional quality level, respectively.

Table 6b,c depict the results of panel estimation for developed/developing countries subpanels. The negative impact of globalization on carbon emissions is stronger in the EU developed economies than in the overall panel, and also developing countries subpanel. The values of regression coefficients are of 0.4-0.5 units higher than in the EU panel. In the case of renewable energy consumption, the effect on carbon emissions is higher in the subpanel of developing countries than in the developed countries and the overall panel. The values of regression coefficients are above the EU levels. The impact of economic growth in the increase of carbon emissions in developed countries is more extensive compared to the overall EU panel and developing countries subpanel. Differences between regression coefficients values from developed countries and the EU panel are ranging from 0.20 to 0.22. Financial development has a different impact on carbon emissions depending on the level of economic development. In the overall panel and developed countries, the impact is negative while in developing countries, it induces pollution. Foreign direct investment and urbanization have positive influences on carbon emissions, and the effect is lower in the developed countries. Developing countries are facing higher levels carbon emissions from these variables compared to developed countries.

Table 6b. Regression estimation - panel of Western and developed EU countries (Austria, Belgium, Cyprus, Denmark, Germany, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden) Dependent variable: lnCO2.

	Model 1		**Model 2**		**Model 3**		**Model 4**	
	FMOLS	**DOLS**	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**
Variables	**-coefficients-**							
lnGDPpc	0.7386*	0.7389*	0.7505*	0.7433*	0.7146*	0.7193*	0.7209*	0.7162*
lnKOF	-1.2446*	-1.2460*	-1.2854*	-1.2642*	-1.1915*	-1.203*	-1.3995*	-1.3703*
LnREC	-0.1353*	-0.1337*	-0.1334*	-0.1324*	-0.1309*	-0.1299*	-0.1300*	-0.1289*
lnFinDev			-0.1086*	-0.0653**				
lnFDI					0.0173*	0.0148*		
lnURB							0.1992*	0.1801*
R-squared	0.5634	0.5564	0.5677	0.7433	0.5653	0.5589	0.5699	0.5612

Note: *p<0.01; **p<0.05. Source: authors' computation based on EViews 12.0 software.

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Table 6c. Regression estimation -panel of Central and Eastern (developing) EU countries (Bulgaria, Estonia, Czech Republic, Croatia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia) Dependent variable: lnCO2.

	Model 1		Model 2		Model 3		Model 4	
	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
Variables	-coefficients-							
lnGDPpc	0.6074*	0.5846*	0.6154*	0.5937*	0.6365*	0.6163*	0.5838*	0.5408*
lnKOF	-0.7845*	-0.7356*	-0.7860*	-0.7419*	-0.8644*	-0.8135*	-0.9502*	-0.8708*
LnREC	-0.3391*	-0.3314*	-0.3342*	-0.3308*	-0.3395*	-0.3396*	-0.3219*	-0.3101*
lnFinDev			0.0682*	0.0518*				
lnFDI					0.0567*	0.0443*		
lnURB							0.2169*	0.2310*
R-squared	0.3793	0.3837	0.3846	0.3879	0.4007	0.4018	0.3884	0.3935

Note: *p<0.01. Source: authors' computation based on EViews 12.0 software.

Regarding the role of institutional quality in differentiating the impact of globalisation, renewable energy and economic growth on carbon emissions, we notice that the results are in some way similar with the level of economic development. Results are displayed in Table 6d,e.

Globalisation has a stronger negative effect on carbon emissions in the high institutional quality countries than in the EU panel and low institutional quality countries subpanel. In the case of renewable energy consumption, the subpanel of low institutional quality countries proves a higher negative impact on carbon emissions. The positive impact of economic growth on carbon emissions is greater in countries with high institutional quality than in the EU panel and in the subpanel of low institutional quality countries. In the subpanel of high institutional quality countries financial development has a larger negative impact on carbon emissions than in the EU panel, while in the subpanel of low institutional quality countries, the effect is not validated. Urbanisation induced more carbon emissions in the low institutional quality countries than in countries of high institutional quality subpanel and the overall panel.

Table 6d. Regression estimation - panel of high institutional quality EU countries (Austria, Belgium, Cyprus, Denmark, Germany, Finland, France, Ireland, Luxembourg, Netherlands, Portugal, Sweden, Estonia) Dependent variable lnCO2.

	Model 1		Model 2		Model 3		Model 4	
	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
Variables	-coefficients-							
lnGDPpc	0.5638*	0.5537*	0.7201*	0.7506*	0.5441*	0.4496*	0.51474*	0.5085*
lnKOF	-0.8123*	-0.7632*	-1.253*	-1.2990*	-0.8013*	-0.5334*	-1.1728*	-1.1754*
LnREC	-0.1172*	-0.1666*	-0.1193*	-0.1439*	-0.0919*	-0.1573*	-0.1094*	-0.1031*
lnFinDev			-0.5428*	-0.3850*				
lnFDI					0.0718*	0.0877*		
lnURB							0.4010*	0.4477*
R-squared	0.3348	0.7855	0.5221	0.8366	0.3475	0.8234	0.3680	0.373

Note: *p<0.01. Source: authors' computation based on EViews 12.0 software.

Table 6e. Regression estimation -panel of low institutional quality EU countries (Greece, Italy, Spain, Bulgaria, Croatia, Czech Republic, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia) Dependent variable: lnCO2.

	Model 1		Model 2		Model 3		Model 4	
	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
Variables	-coefficients-							
lnGDPpc	0.3761*	0.4123*	0.3622*	0.2213*	0.3973*	0.4038**	0.2350*	0.3224*
lnKOF	-0.2617*	-0.3571**	-0.2202*	-0.1582**	-0.3096*	-0.3352**	-0.0848**	-0.2401*
LnREC	-0.3512*	-0.3401*	-0.3518*	-0.2749*	-0.3593*	-0.3413*	-0.2926*	-0.3469*
lnFinDev			0.0352*	0.0569**				
lnFDI					0.0165*	0.0165		
lnURB							0.9284*	0.7195***
R-squared	0.5930	0.9306	0.5955	0.9137	0.5951	0.9821	0.9291	0.9929

Note: *p<0.01; **p<0.05; *** p<0.1. Source: authors' computation based on EViews 12.0 software.

4.6. Panel Causality Test

The results of the panel causality test are displayed in Table 7. Bidirectional causal relationships are identified between carbon emission and GDP per capita, renewable energy consumption financial development, and urbanization. Unidirectional causalities running from globalization to carbon emissions and from carbon emissions to FDI are also validated

Table 7. Results of Dumitrescu and Durlin causality test.

Null Hypothesis (H0)	z-bar	p-value	Conclusion
LnCO2 does not Granger-cause *lnKOF*	7.2026	0.000	KOF→CO2
lnKOF does not Granger-cause *lnCO2*	1.5211	0.1282	
LnCO2 does not Granger-cause *lnGDPpc*	10.2093	0.000	GDPpc→ CO2
lnGDPpc does not Granger-cause *lnCO2*	6.3591	0.000	CO2→ GDPpc
LnCO2 does not Granger-cause *lnREC*	5.1745	0.000	REC→CO2
lnREC does not Granger-cause *lnCO2*	17.8105	0.000	CO2→REC
lnCO2 does not Granger-cause *lnFinDev*	4.8424	0.000	FinDev→CO2
lnFinDev does not Granger-cause *lnCO2*	2.0653	0.0389	CO2→ FinDev
lnCO2 does not Granger cause *lnFDI*	0.3700	0.7114	
lnFDI does not Granger cause *lnCO2*	3.8457	0.0000	CO2→FDI
lnURB does not Granger-cause *lnCO2*	12.4023	0.000	CO2→ URB
lnCO2 does not Granger-cause *lnURB*	34.2891	0.000	URB→CO2

Note: lag = 1; Source: authors' computation based on Stata 15 software.

The identified causality from globalization to carbon emissions is consistent with the findings of Zaidi et al. [26] for APEC countries, and Sheraz et al. [71] for BRI countries, as well as Wang et al. [55] for OECD countries. Ayeche et al. [18], Amin and Song [73], Bosah et al. [83], Habiba et al. [115], and Jiang and Yu [163] revealed also a bidirectional causality between economic growth and carbon emissions. Our conclusion regarding the bidirectional influence between renewable energy and carbon emissions is in line with the findings of Amin and Song [73] for South-Asian countries and Bosah et al. [83] for a global sample of countries and Sheraz et al. [71]. The bidirectional causality between financial development and carbon emissions has also been highlighted by Azam et al. [60] and Sheraz et al. [71]. The result of the bidirectional causality between urbanization and carbon emissions is consistent with the conclusions of Azam et al. [60] and Amin and Song (2023) [73].

5. Discussion

Globalisation and renewable energy use are found as reducing factors of carbon emissions in the overall panel of 26 EU countries and also, in the two sub-panels (developed/developing and high/low

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institutional quality countries). This is in line with findings of Adebayo et al. [148] for BRICS countries and also of Addai et al. [11] for the relationship between globalisation and environmental quality in Germany. It should also be mentioned that the same relationship between renewable energy use and carbon emissions was identified by Ansari et al.[31], Alola and Joshua [41], Murshed et al.[51] Saidi and Omri [62], Jebli et al. [63], Khan et al. [64], Kirikkaleli and Adebayo [65]; Adebayo et al. [67], Wu et al.[68], Amin and Song [72], Sun et al.[73], Li et al. [74], Salahuddin et al.[75], and Acheampong et al. [156]. The decreasing effect of globalisation on carbon emissions is weakening in developing and low institutional quality countries than in the overall panel and developed and high institutional quality countries. It suggests that is more space for specific efforts and effective measures (i.e., carbon taxation, strict environmental rules) to be drawn and applied by strength institutions in order to mitigate pollution in these countries. On the other hand, institutional policies should take into consideration that globalisation process is not always targeted towards pollution mitigation, the risk of transfer in other countries of pollution-intensive operations through business globalisation process is real. We found that the decreasing effect of renewable energy on carbon emissions is stronger in developing countries than in the developed ones. It is pointed out that renewable energy use could be beneficial for environment in these countries, putting forward the idea that further efforts must be considered in order to continue the extension of renewable sources in the energy consumption mix. It should be noted that, six of these 11 countries (Latvia, Estonia, Croatia, Lithuania, Romania and Slovenia) record higher levels of the share of renewable energy in the final consumption (23-42%) which is above the European Union average, between 2004-2021, according to Eurostat data [164]. It is also true, that in the subpanel of Western developed countries, also five of them (Austria, Denmark, Portugal, Finland and Sweden) are recording very high levels of renewable energy in the final consumption (34-62%) in the same period of time. In countries with low institutional quality, the carbon emissions-reducing effect of renewable energy use is greater than in countries with high institutional quality, suggesting that institutional quality has not yet played a decisive role in the expansion of renewable energy use.

Economic growth induced the rise of carbon emission the panel of EU countries and all sub-panels. This is consistent with the majority of studies focused on this nexus [11,52,54,57,60,65,67,73,77,79–81,139,157]). These findings suggest, once more, the need to decouple economic growth from pollution in the European Union. The structure of economy must be clearly shifted from traditional to clean energy sources (wind, solar, hydropower, biomass, and geothermal) and appropriate energy policies must be shaped in support of energy intensity and efficiency and ongoing efforts to extend the funding of R&D activities in clean technologies.

Financial development alleviates carbon emissions in the overall panel of the EU countries, result that is in line with findings of Vatamanu and Zugravu [12], Khan and Ozturk [90], Kim et al. [152], and Khan and Rana [157]. This in contradiction with the results of Horobeț et al. [14] for the EU countries showing a positive impact of financial development on carbon emissions. In the subpanel of developing EU countries financial development has a positive and significant impact on carbon emissions, as it was found by Jiang et al. [93] and Acheampong et al. [92]. The same effect of financial development on carbon emissions is identified in the subpanel of low institutional quality EU countries. The alleviating effect of financial development is stronger in the subpanel of developed and high institutional quality, suggesting that: (1) low level of income and financial development increase carbon emissions while high level of income decrease them, as it revealed by Ehigiamusoe and Lean [85], and (2) institutional quality can moderate the effect of financial development on carbon emissions [89,152,158].

Foreign direct investment is found as stimulating factor of carbon emissions in the overall panel and all subpanels. This result is consistent with previous relevant studies [15,60,97,101,157]. The detrimental effect of foreign direct investment on environmental quality is higher in the EU developing countries than in the overall panel and the subpanel of developed countries., as it was highlighted by Jahanger et al. [33]. This suggests the need for more effective European policies stimulating the attraction of green foreign investment, investment in sectors with low-carbon energy and, also more restrictive legal norms on environmental degradation. It is also worth mentioning

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that, as Wang et al. [101] noticed, low-income countries should promote economic development in order to gain the capacity to alleviate the increasing pollution due to the inward FDI flows, while strengthening environmental regulation.

Urbanisation increased carbon emissions in the overall EU panel and all sub-panels as found by Al-Mulali et al. [19], Islam et al. [23], Azam et al. [60], Raihan and Tuspekova [85], and Sun et al. [73]. The effect is stronger in the subpanel of low institutional quality countries and lower in the high-income countries. As it is suggested by Sun et al. [73], inadequate planning of buildings and constructions, lack of restrictive environmental rules, informal settlements or improper planning of urbanisation process. Therefore, the root causes of environmental pollution induced by urbanisation should be investigated, alongside with more restrictive environmental regulation and green projects for sustainable urbanisation. Wang et al. [165] proved that high income OECD countries have been already able to decouple urbanisation from carbon emissions and it is confirmed an inverted U-shaped relationship between these two variables. In first stages, urbanisation increase carbon emissions through economic growth and residential energy consumption, but when the urbanisation exceeds the ”consumption effect” is exceeded, through improving energy efficiency and restrain industrial energy consumption, it results the ”agglomeration effect”. Based on these findings, it is suggested that promoting the urbanisation process in the EU countries, improving energy efficiency, optimizing the energy consumption structure, industrial upgrading and reducing carbon intensity, will induce the scale effect and conduct to carbon emission reduction.

6. Conclusions and Policy Recommendations

The present study intended to determine the links between globalisation, renewable energy consumption, economic growth and carbon emissions for 26 EU countries using panel data covering the period of 1990-2020. A set of control variables (financial development, foreign direct investment and urbanisation rate) is also included in the empirical analysis. We applied a cross-sectional approach to examine the dependence among the variables, then the stationarity properties are examined using second-generation unit root tests (CIPS and CADF). The existence of cointegration relationship between the considered variables is identified through the Westerlund test and the regression coefficients are estimated by FMOLS and DOLS models. We conducted separate regressions for the overall panel of 26 EU countries and also for subpanels of developed/developing and high/low institutional quality countries. Finally, the causality between variables is identified with the Dumitrescu-Hurlin test.

We found that the carbon emissions-reducing effect of globalisation is stronger in the panel of developed and high institutional quality countries than in the developing and low institutional quality ones. Renewable energy consumption induced decreasing levels of carbon emissions in the overall panel and in all subpanels but the negative impact is more intense in the developing and low institutional quality countries. GDP per capita is found as a contributor to carbon emissions growth in the overall panel and also in all subpanels, a wider effect being revealed in the developed countries. Financial development induced a decreasing impact on carbon emissions, while a foreign direct investment and urbanisation caused their increase in the overall panel of the 26 EU countries. The decreasing effect of financial development on carbon emissions is maintained in developed and high institutional quality countries while in developing and low institutional quality countries there is a reverse effect. The increase of carbon emissions determined by foreign direct investment is revealed in the overall panel, and also in the two subpanels. The impact is stronger in developing countries while in the low institutional quality countries it is not statistically significant. Urbanisation caused the increase of carbon emissions in the EU panel and also in the two subpanels, the increasing effect being stronger in the developing and low institutional quality countries than in the developed and high institutional quality ones. To sum up, the relationship between the variables under consideration (globalisation, renewable energy, economic growth, financial development, foreign direct investment, urbanisation) and carbon emissions depends in a large extend on the economic development and institutional quality level. Economic development and high institutional quality are mainly associated with a higher positive impact of globalisation and financial development and a lower negative impact of foreign direct investment and urbanisation on carbon emissions reduction. In the case of renewable energy consumption, the reduction effect on carbon emissions is higher in developing and low institutional quality countries. Unidirectional causalities relationships were identified from globalisation to carbon emissions and from carbon emissions to foreign direct investment and bidirectional relationships between economic growth, renewable energy consumption, financial development and carbon emissions.

As overall conclusion, globalization and renewable energy contributed to the decreasing levels of carbon emissions during 1990 to 2020 in the European Union countries. In the general backwards trend of carbon emissions (based on World Bank data [8],[118]) the decreasing yearly rates in the EU are highly accelerated in last years (after 2009). Carbon emissions decreased in the EU with 30.91% (in kilotons) and 35.13% (in metric tons per capita) in 2020 compared to 1990 (computation based on World Bank data [8],[118]). This suggests that globalization and renewable energy, in complementarity with other factors, could have a beneficial contribution to the achievement of carbon neutrality in the European Union countries by 2050.

The study's results are suggesting some directions for the European policies, in the frame of the European Green deal and targets of climate-neutrality by 2050. Considering our findings, we recommend: (i) Globalisation must be promoted through: the improvement of banking system, overall, stimulating the financial development, encouraging the development of green innovation, and expansion of a cleaner energy sector; it is also needed to enhance institutional quality by reducing corruption, ensuring property rights and business freedom; (ii) More effective policy measures to extend the investment in renewable energy sources (provision of financial instruments for energy-saving projects, incentive through fiscal policies, grants to households) are needed; (iii) The increasing energy demand needed for higher level of economic growth should be covered by expanded financial incentives for investment in renewable energy sources, updated infrastructure and a larger R&D budget in developing countries for eco-friendly power sources, alongside with carbon pricing, tariffs and advancement of industry 4.0; (iv) Financial development could be seen as a means of decreasing carbon emissions in the EU countries (as it is also suggested by Horobeț et al. [14]). For developed countries, further efforts to enhance the restraining effect on carbon emissions are needed. Strengthening the financial system and construction of capital markets would create innovative financial instruments meant to support investments in green business and energy-saving business, investment in research and development and industrial restructuring for energy intensity decrease. In developing countries, there is a need for: effective regulations of activities of financial institutions to prevent the financing of pollutant activities; development of capital markets; improving the efficiency in the allocation of financial capital; promoting technological innovation through financial capital; subsidies for entrepreneurial activities to introduce environmental technologies. In all countries, financial resources should be directed towards investments in green transportation, green energy, green industry, thus building the green economy; (v) European policies should be focused on tax and trade policies for foreign investors related to: green/clean technology investment, green R&D activities and integrate the perspective of the EU developing countries where more precaution and more strict rules and regulations are needed regarding the inflow of FDI into country, in order to not create an adding harmful effect on environment quality. Additionally, in developing countries efforts should be made to promote carbon-reducing businesses in sectors with high energy consumption, and monitor foreign direct investment in clean industries. Such business should be assisted in advancing production technology and reducing carbon emissions, as it suggested by Javed et al. [81]. Moreover, as Wang et al. [101] pointed out, developing economies should gain capacity to master pollution and remediate excessive pollution; (vi) governments should invest more in green technologies meant to reduce carbon emissions in urban areas and promote fiscal measures, financial incentives in order to encourage people to switch to cleaner energy. Financial institutions might give funding support to buildings developers in their green buildings' projects and, also to population for homes renovating or changing in order to meet green criteria (as it suggested by Raihan and Tuspekova [85]); (vii) institutional quality is essential to better the environmental quality on the long-run, therefore, mainly, developing countries need to further strengthen the quality of their institutions (i.e., control corruption, reducing the level of bureaucracy, improving the political stability, more restrictive environmental rules) in order to extend their clean energy sources and achieve sustainable development.

For a deeper analysis and more detailed results, future research may examine the effect of all globalization dimensions (economic, financial, political) and types (de jure/de facto) on carbon emissions in the EU countries or taking into consideration other proxies for environmental quality (i.e., ecological footprint, carbon footprint). It would be also useful to explore the effect of a mix non-polluting energies consumption (i.e., renewable and nuclear energy, as it is suggested by Saidi and Omri [62] in their study on OECD countries) on carbon emissions.

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