

Article

The Link between Human Development, Foreign Direct Investment, Renewable Energy, and Carbon Dioxide Emissions in G7 Economies

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Abstract: This research evaluates the determinants of pollution emissions, considering the human development index, international trade, renewable energy, and foreign direct investment (*FDI*) as explanatory variables. This study tests the relationship between trade intensity and *FDI* on carbon dioxide emissions, considering the arguments of the pollution haven hypothesis (*PHH*) versus halo pollution (*HP*). The econometric strategy applies panel data (fixed effects, random effects), a generalised linear model (Gamma), panel cointegration models such as FMOLS and DOLS, the ARDL panel model, and the panel quantile regressions to data from the G7 countries from 1990 to 2019. Before using econometric models, this investigation considers preliminary tests such as the panel unit root test (first and second generation) and the cointegration test. The econometric results show that human development decreased pollution emissions. In addition, renewable energy improves air quality and aims to reduce climate change. The inverted environmental Kuznets curve also supports the results when evaluating the relationship between the human development index and carbon dioxide emissions.

Keywords: panel data; unit root test; cointegration; CO₂ emissions



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1. Introduction

In recent years, several studies (e.g., Saqib et al. [1]; Liu et al. [2]) have evaluated the environmental Kuznets curve (EKC) as applied to the G7 group of countries (United States of America, Germany, Canada, Japan, Italy, United Kingdom, and France).

Several international organisations, including the International Monetary Fund (IMF) and the United Nations (UN), have stated that the G7 economies are considered the most industrialised countries in the world economy. Data published by the World Bank and the human development report produced by the United Nations in the last two decades indicate that these countries present high levels of per capita income and human development. This has resulted in the academic community's interest in studying this group of countries. From the various summits on the environment and sustainability, the G7 group has shown interest in contributing to decarbonisation, where the objective will be to increasingly use cleaner energy in the future. Referring to the interest in studying the G7 group of countries, our investigation uses recent econometric research methods to test the arguments of the environmental Kuznets curve (EKC) and pollution haven hypotheses versus the halo pollution hypothesis.

As referred to in the EKC literature, economic growth variables (income per capita and squared income per capita) evaluate the level of industrialisation of one economy or a group of economies. More recently, the EKC studies have used renewable energy consumption to test the effect on carbon dioxide emissions.

This research considers the *EKC* arguments to examine the relationship between human development (*HDI*) and carbon dioxide emissions; as control variables, we used renewable energy, openness to trade, and *FDI* in the G7 economies group.

There is a very relevant number of papers on using the explanatory variables of foreign direct investment (*FDI*) and the impact of renewable energies on carbon dioxide emissions. Thus, it is observed that the consumption of renewable energy reduces polluting emissions. Regarding the effect of *FDI* on carbon dioxide emissions, two possible positions can be observed. *FDI* can contribute to eliminating pollution emissions, resulting in cleaner energy and an improved quality–price relationship. On the other hand, another position demonstrates that *FDI* is associated with high pollution levels, as explained by the pollution haven hypothesis (*PHH*).

As the recent literature demonstrates (e.g., Saqib et al. [1]; Liu et al. [2]; Katircioglu [3]; Isik et al. [4]), the dependent variables most used by empirical studies for pollution levels have been carbon dioxide emissions or the carbon footprint. Nevertheless, not all panel studies validate the *EKC* for the G7 economies. However, studies show the importance of renewable energies in reducing environmental damage and improving air quality.

Regardless of the geographic area or the organization of the data (panel data or time series), the studies by Mahmoodi and Dahmardeh [5], Leitão et al. [6], and Gyamfi et al. [7] demonstrate the importance of continuing to study the *EKC*. Furthermore, in addition to the relationship between economic growth and polluting emissions, it is noted that in recent years, researchers have more frequently introduced into econometric models as explanatory variables not only the consumption of fossil energies but also the consumption of renewable energies and the energetic capacity. Then, we observe in the literature that the impacts of international trade and *FDI* can be explained by the pollution haven hypothesis (*PHH*), halo pollution, and the environmental Kuznets curve (*EKC*). These theories consider the relationships between countries in the northern and southern hemispheres (e.g., Cole [8]; Leitão [9]; Leitão et al. [10]). Nevertheless, we can also refer to perfect competition (Heckscher–Ohlin) and monopolistic competition (scale economies, industrial concentration) to explain the linkages between intra-industry trade, *FDI*, and environmental issues.

In this context, the empirical study of Apergis et al. [11] applied panel data between BRICS and OECD countries using bilateral *FDI*. Then, Apergis et al. [11] confirmed the perception of the pollution haven hypothesis was validated between the BRICS Denmark and the United Kingdom. However, this study showed that the impact of bilateral *FDI* of BRICS on France, Germany, and Italy is explained by the pollution halo hypothesis, i.e., improved environment and air quality.

This investigation seeks to answer three questions: (i) What is the relationship between the human development index and carbon dioxide emissions in G7 countries? (ii) To what extent is the hypothesis of an environmental Kuznets curve verified between the human development index and carbon dioxide emissions for the G7 group of countries? (iii) Does renewable energy promote the air quality in the G7 group?

To this end, the paper presents the following structure: A Literature Review in Section 2, followed by Data and Methodology in Section 3. Analysis of the results appears in Section 4, Discussion in Section 5, and finally, Conclusions in Section 6.

2. Literature Review

In this section, we present different studies applied to different countries and regions using different econometric strategies (panel data or time series), given relevance to the experience of the G7 countries. In this context, we present the main conclusions of recent studies, considering the linkages between economic growth, human development index, trade, renewable energy, foreign direct investment (*FDI*), and pollution emissions.

This section is organised into three subsections. First, we evaluate the interdependent relationships between renewable energy, economic growth, and pollution emissions. Second, we make a brief inference about international trade and pollution emissions. Finally, we look at the link between *FDI* and carbon dioxide emissions.

2.1. The Links between Renewable Energy, Economic Growth, and Pollution Emissions

According to environmental Kuznets curve (EKC) assumptions, the relationship between economic activities and carbon dioxide emissions, i.e., income per capita, is positively associated with CO₂ emissions and squared income per capita is negatively impacted by carbon dioxide emissions. On the other hand, renewable energy negatively impacts carbon dioxide emissions, showing that using renewable energy aims to improve environmental degradation.

The increased use of renewable energy (e.g., Apergis et al. [11]; Szetela et al. [12]; Acheampong et al. [13]; Chen et al. [14]; Raihan [15]; Hasanov et al. [16]) demonstrates that carbon dioxide emissions correspondingly decrease. In fact, for several decades, studies of energy and environmental economics have introduced non-renewable energy consumption into econometric models as an independent variable. However, with the various international summits on the environment, this contributes to the use of renewable energy and the definition of common objectives related to improving the environment.

The experience of the Philippines was investigated by Raihan [15] using the ARDL model and the cointegration model (DOLS), and the econometric results showed that renewable energy, agricultural productivity, and forest area are negatively correlated with carbon dioxide emissions, demonstrating that these variables improved the Philippines economy's environment.

The relationship between economic growth and EKC has been debated over the years (e.g., Leitão et al. [10] Grossman and Krueger [17]; Pata et al. [18]; Fuinhas et al. [19]). The literature argues that economic growth promotes climate change. However, from a certain point on, the economy becomes more aware of environmental issues from a medium- and long-run perspective.

Balogh [20] considered a non-EU group of countries using panel cointegration models. The econometric results demonstrated that the EKC hypothesis was supported in this study. Furthermore, the dummy variables of the Paris Agreement and Kyoto Protocol, or regional economic integration as in EFTA, MERCOSUR, and ASEAN, are negatively correlated with carbon dioxide emissions, showing that carbon dioxide emissions decrease and, consequently, the environment improves.

For instance, the experience of MENA economies was investigated by Kostakis et al. [21] with panel data. Considering the results with the cointegration panel, the authors demonstrate that the environmental Kuznets curve is valid in the MENA region. Houran and Mehmood [22] evaluated the EKC considering the G20 economies. The panel ARDL model demonstrated that the environmental Kuznets curve hypothesis explain the relationship between economic growth and pollution emissions.

The Visegrad experience was considered by the study of Leitão et al. [6], where the authors analysed the environmental Kuznets curve and the economic growth. The equation of EKC using a panel ARDL model demonstrated that, in the short run, the economic growth variables are positively and negatively impacted by CO₂ emissions for Visegrad countries, except Hungary. However, considering the long-run effects, the variables of non-renewable energy (energy consumption) and FDI (foreign direct investment) positively affect pollution emissions, validating the pollution haven hypothesis (PHH) theory.

The empirical studies are applied to G7 economies considering the linkages of ecological variables, renewable energy, and carbon dioxide emissions. Nevertheless, as seen from the survey, the empirical studies are not unanimous regarding the relationship between economic growth and carbon dioxide emissions, i.e., not all studies validate the environmental Kuznets curve (EKC) for the G7 countries. Next, we present a selection of analyses applied to G7 economies.

For example, the effects of innovation and renewable energy on ecological footprints used by G7 countries were investigated by Saqib et al. [1] using a cross-sectional ARDL model covering the period from 1990 to 2020. Based on the long run, the authors found that the environmental Kuznets curve (EKC) hypothesis is valid. The econometric results also

demonstrated that policymakers should consider human capital. The authors also found a negative association between human capital and carbon dioxide emissions.

Following the position of some studies such as Szetela et al. [12], Bezić et al. [23], and Sezgin et al. [24], we evaluate the impact of the human development index (*HDI*) on pollution emissions, and it is an alternative way of considering the *EKC* arguments.

The studies found a negative association between the human development index and pollutant emissions, demonstrating that the higher the *HDI*, the lower the polluting emissions. The empirical study by Akbar et al. [25] considers the relationships between health expenditure, the human development index, research and development, and population growth for OECD countries using a panel VAR (vector autoregressive). Considering only the vector for the carbon dioxide emissions equation as a dependent variable, it is observed that the human development index makes it possible to reduce carbon dioxide emissions. Based on the experience of OECD countries, the investigation by Opoku et al. [26] demonstrates that the human development index improves air quality and reduces polluting emissions.

From the studies mentioned, it is observed that there is a gap, i.e., the studies have yet to use the squared human development index on carbon dioxide emissions. The use of the human development index (*HDI*) to test *EKC* is still in its incipient stages.

The investigation of Ike et al. [27] tested the *EKC* in G7 economies; the authors applied panel cointegration, and the econometric results showed that the *EKC* is valid for all G7 economies. Moreover, renewable energy and fuel prices are negatively correlated with carbon dioxide emissions, i.e., the aim of improving the environment. A different point of view is the empirical study of Katircioglu [3], showing that an inverted curve of the *EKC* exists only in France and Italy.

The research of Khalfaoui et al. [28] considers the effect of economic growth on pollution emissions to G7 economies using an econometric strategy wavelet coherence. The results demonstrate that carbon dioxide emissions directly impact economic growth.

Considering the correlation between environmental degradation via ecological footprint and economic growth as a strategy, a panel causality was investigated by Yilanci and Ozgur [29], and they only confirmed the *EKC* to Japan and USA.

The causality between imports and economic growth from 1970 to 2019 was analysed by Usman and Bashir [30] using the econometric methodology Granger causality. This study found a bidirectional cause among the G7 economies, India, and China variables.

Liu et al. [2] tested the *EKC* considering carbon dioxide and SO₂ emissions. They concluded that the *EKC* hypothesis (income per capita and square income per capita) is valid for G7 economies when the authors used SO₂ emissions as the dependent variable.

The empirical research of Khan et al. [31] tested the economic complexity, renewable energy, and energy consumption on ecological footprint using panel cointegration, and they found that economic complexity and square economic complexity are positively and negatively correlated with the environmental footprint, validating the *EKC* hypothesis. Moreover, the authors showed that renewable energy decreases ecological problems.

Isik et al. [4] used an econometric strategy AMG estimator for evaluating the *EKC* in G7 countries, and the authors found that only France had an inverted U curve. However, as with previous studies applied in this case, renewable energy again improved the environment. The study of Yilanci and Pata [32] assessed the link between fiscal policy and CO₂ emissions, and the relationship between economic growth and pollution emissions. According to the *EKC* hypothesis, the association between economic growth and carbon dioxide emissions is invalid. However, the authors found the support of *EKC* by fiscal policy to be an inverted U curve.

The recent article of Dogan et al. [33] considered the G7 economies using panel cointegration (FMOLS). The empirical results show that economic growth is positively and negatively correlated with CO₂ emissions, validating the *EKC*. Furthermore, the authors found a similar relationship between the index of economic complexity and carbon dioxide emissions and a negative association between renewable energy and CO₂ emissions.

From the literature review presented to this group of countries, it is observed that not all studies have validated the environmental Kuznets curve (*EKC*) hypothesis, either through carbon dioxide emissions or other polluting emission agents.

2.2. The Link between International Trade and Pollution Emissions

As Cole [8] demonstrated, there exists a vast empirical literature that has tested the correlation between international trade and pollution emissions via the environmental Kuznets curve (*EKC*) and the pollution haven hypothesis (*PHH*). The article of Cole [8] illustrated that an economy that practices pollution intensity could hardly validate the hypothesis of *EKC*, i.e., reduce carbon dioxide emissions and greenhouse effects. In addition, *PHH* theory demonstrates that the home country exports products with higher pollution, i.e., without using renewable and cleaner energies.

Various studies (Leitão [9], Roy [34], Leitão and Balogh [35], Leitão et al. [6]) demonstrate that intra-industry trade (*IIT*) has a negative impact on carbon dioxide emissions, indicating that this type of trade makes it possible to decrease climate change and improve quality of life and sustainability. However, the alternative hypothesis shows that international trade, explained by inter-industry trade, is associated with theories of advantages, harms the environment, and damages air quality.

The empirical study of Leitão et al. [6] considers the effect of the bilateral intra-industry relationship between Portugal and Spain on Portuguese carbon dioxide emissions. The empirical research showed that intra-industry trade decreased pollution emissions when the authors used a panel ARDL (autoregressive distributed lag) model. Moreover, the Portuguese and Spanish renewable energy variable aims to reduce environmental degradation. Lastly, foreign direct investment is negatively correlated with CO₂ emissions, and this effect is explained by the halo pollution hypothesis, showing that foreign direct investment is explained by innovation and product differentiation.

Osabuohien-Irabor and Drapkin [36] considered the experience of the EU to test the effect of trade and foreign trade on CO₂ emissions. The authors used a panel ARDL model, and in the long run, the empirical results showed that outward *FDI* and exports are negatively correlated with carbon dioxide emissions; these variables improved the environment.

The experience of 90 countries using a panel data approach was investigated by Yahya and Lee [37]. The study applied panel quantile regressions as an econometric strategy. Considering carbon dioxide emissions as the dependent variable, Yahya and Lee [37] found that exports and agricultural production contributed to decreasing pollution emissions.

The study of Thi et al. [38] considers the nexus between renewable energy, tourism demand, international trade, innovation, and carbon dioxide emissions for 53 economies with different developments. The econometric results reveal that renewable energy, international trade, urban population, innovation, and foreign direct investment aim to decrease pollution emissions. In addition, Thi et al. [38] demonstrated that tourism arrivals and economic growth stimulate climate change and greenhouse emissions.

Leitão and Balogh [35] examined the agricultural sector, considering the impact of intra-industry trade (*IIT*), renewable energy, arable land, and income per capita on pollution emissions for the European Union experience. The results demonstrated that *IIT* and renewable energy aim to decrease pollution emissions. However, the arable land and income per capita positively correlate with CO₂ emissions, and they concluded that these variables stimulate pollution emissions and climate change.

2.3. The Role of Foreign Direct Investment on Pollution Emissions

The empirical studies of Leitão et al. [6], Pata et al. [18], Rahman et al. [39], and Balsalobre-Lorente et al. [40] consider the impact of foreign direct investment (*FDI*) and carbon dioxide emissions.

As a rule, the dominant hypothesis relates to the fact that *FDI* reduces the effects of pollution, which is usually justified by the innovation and differentiation of the products.

However, many studies have found a positive correlation between *FDI* and carbon dioxide emissions, demonstrating that *FDI* accentuates climate change.

The experience of ASEAN countries was investigated by Pata et al. [18] using a panel ARDL model. The results showed that tourism and foreign direct investment (*FDI*) positively correlated with carbon dioxide emissions. Therefore, these variables demonstrate that climate change is increasing with tourism demand and *FDI*. In addition, international trade and renewable energy revealed that these variables improved environmental policy.

The empirical study of Kayani et al. [41] used panel cointegration to test the effects of *FDI*, renewable energy, urbanization, tourism arrivals, and economic growth on carbon dioxide emissions. The econometric results demonstrated that *FDI*, urbanization, economic growth, and tourism stimulate environmental degradation.

The recent study of Wencong et al. [42] considers the link between *FDI* and renewable energy in context of the environmental Kuznets curve (*EKC*), considering the transition economies. The authors used the panel ARDL model, panel quantile regressions, and panel causality as strategies. The long-run results obtained by panel ARDL showed that *FDI* positively affects pollution emissions.

The linkages of economic complexity, renewable energy, foreign direct investment, and pollution emissions applied to BRICS were investigated by Balsalobre-Lorente et al. [40]. The authors considered a panel data approach, and the results based on panel cointegration models showed that economic complexity validated the *EKC* hypothesis. In addition, the variable of renewable energy decreased pollution emissions. Nevertheless, foreign direct investment is positively correlated with carbon dioxide emissions with statistical significance.

3. Data and Methods

The G7 group of countries (United States of America, Germany, Canada, Japan, Italy, United Kingdom, and France) for the period from 1990 to 2019 was considered in this research. The variables of the human development index (*HDI*), renewable energy (*REW*), openness to trade (*TRADE*), and foreign direct investment (*FDI*) on carbon dioxide emissions were used in this research.

The econometric models used were panel data, Random effects (RE), Fixed effects (FE), Generalised Linear Model (GLM) via Gamma estimator, panel cointegration, fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and the PMG-ARDL model, since this model considers both the short- and long-run. In addition, the Hausman test allowed us to choose the more appropriate estimator (H_0 : Random effects versus Fixed effects). The panel data were analysed and tested to determine if the variables under study were stationary and had no multicollinearity problems. Cointegration tests between the variables were also applied before proceeding with the estimation models.

After presenting the results of the general model, we tested the assumptions of the *EKC* equation using the relationship between the human development index (*HDI* and HDI^2) and carbon dioxide emissions using the panel quantile regressions.

In this context, we present the hypotheses that will be considered in an empirical section based on the literature review.

H1. Does the human development index aim to decrease pollution emissions?

As the study by Hussain and Dey [43] suggested, the link between income per capita and carbon dioxide emissions has been criticised in the literature more recently. However, when carrying out an analysis of the state of this association, it is observed that researchers have been using other variables such as the economic complexity index (e.g., Leitão [9]; Dogan et al. [33]; Romero and Gramkow [44]) or the human development index (e.g., Bezić et al. [23]; Sezgin et al. [24]; Hussain and Dey [43]; Majewska and Gierałtowska [45]).

Regarding the human development index (*HDI*), a negative effect is expected, as demonstrated by the studies by Bezić et al. [23], Sezgin et al. [24], Hussain and Dey [43], and Majewska and Gierałtowska [45].

- *HDI*—Human development index from Human Development Reports, United Nations. This index involves life expectations, education, and the GINI index.

H2. Do renewable energies improve environmental degradation in the G7 economies?

The recent empirical studies as in Gyamfi et al. [7], Leitão et al. [10], Khan et al. [31], Dogan et al. [33], and Chu and Le [46] continue to demonstrate that renewable energy aims to decrease carbon dioxide emissions and the improvement of air quality.

- *REW*—Renewable energy consumption is a share of total energy consumption sourced by Word Bank indicators.

H3. How far can international trade and foreign direct investment improve the environment in the G7 economies?

According to the literature review (e.g., Saqib et al. [1]; Ike et al. [27]; Khan et al. [31]; Leitão et al. [6]; Ata and Likhachev [47]), it is possible to observe that international trade and foreign direct investment may have a positive (pollution haven hypothesis) or negative (pollution halo hypothesis) association with carbon dioxide emissions.

The pollution haven hypothesis (*PHH*) is explained by trade and foreign investment when the firms look for markets where the regulation of environmental work rules are incipient, which are associated with high pollution emissions. On the contrary, the pollution halo hypothesis states that bilateral trade and foreign investment are related to sustainable practices and decarbonization.

- *FDI*—Foreign direct investment, net inflows (% GDP) by Word Bank indicators.
- *TRADE*—Exports plus imports divided by GDP by Word Bank indicators.

Figure 1 presents the econometric strategy applied in this study.

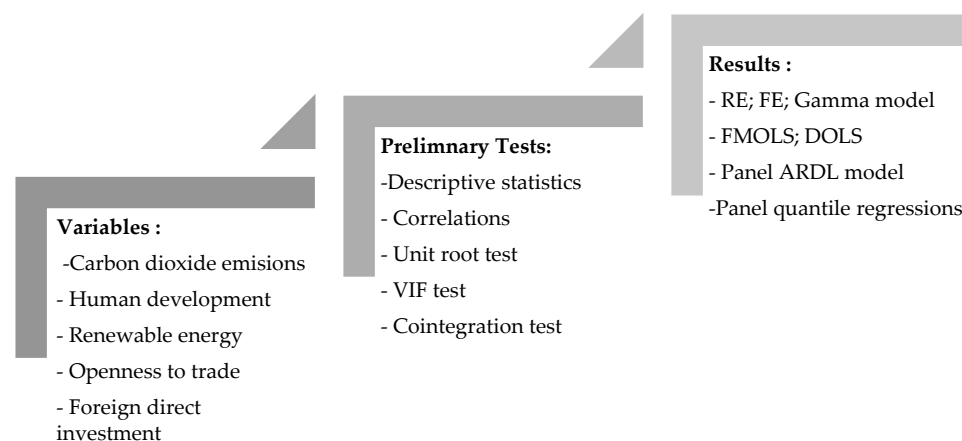


Figure 1. Econometric strategy.

After presenting the variables and hypotheses under study, we formulate the following equation:

$$CO_2 = f(HDI; TRADE; REW; FDI) \quad (1)$$

The human development index (*HDI*) presents a negative effect on pollution emissions, showing an improvement in pollution emissions. The studies of Bezić et al. [23], Sezgin et al. [24], Akbar et al. [25], Opoku et al. [26], Hussain and Dey [43], and Majewska and Gierałtowska [45] show that the human development index reduces carbon dioxide emissions.

Also widely referred to in the literature (e.g., Thi et al. [38]; Kayani et al. [41]; Raihan [15] in recent years, renewable energies (*REW*) allow for decreased climate change and improved air quality.

Subsequently, the linkage between foreign direct investment (*FDI*) and carbon dioxide emissions is explained by two different positions (Leitão et al. [10], Pata et al. [18]; Rahman et al. [39]; Balsalobre-Lorente et al. [40]). When *FDI* is negatively correlated with CO_2 emissions, empirical studies argue that *FDI* decreases climate change and is explained by innovation and product differentiation. However, we observed in the literature that several studies found a positive association between *FDI* and carbon dioxide emissions, showing that *FDI* stimulates pollution emissions.

Next, we present the general model to be estimated in this research:

$$\text{LogCO}_2 = \beta_0 + \beta_1 \text{HDI} + \beta_2 \text{LogREW} + \beta_3 \text{LogTRADE} + \beta_4 \text{LogFDI} + \mu it \quad (2)$$

Thus, $\beta_1 \text{HDI} < 0$; $\beta_2 \text{LogREW} < 0$; $\beta_3 \text{LogTRADE} > 0$, or $\beta_3 \text{LogTRADE} < 0$; $\beta_4 \text{LogFDI} < 0$, or $\beta_4 \text{LogFDI} > 0$, where the dependent variable is carbon dioxide emissions (LogCO_2), and μit represents the random residual term or error. The carbon dioxide emissions in Kt come from World Bank Indicators.

Note that the expected signals for the *FDI* and *TRADE* coefficients can either assume positive (pollution haven hypothesis) or negative (pollution halo hypothesis) signals.

Based on Equation (2), we present the environmental Kuznets curve (*EKC*) argument applied to the relationship between the human development index and carbon dioxide emissions:

$$\text{LogCO}_2 = \beta_0 + \beta_1 \text{HDI} + \beta_2 \text{LogHDI}^2 + \beta_3 \text{LogREW} + \mu it \quad (3)$$

Therefore, $\beta_1 \text{HDI} > 0$; $\beta_2 \text{LogHDI}^2 < 0$; $\beta_3 \text{LogREW} < 0$.

According to *EKC* assumptions, a positive association between the human development index and carbon dioxide emissions is expected. However, when countries are concerned about environmental issues and decarbonization, a negative relationship is expected between the squared human development index and carbon dioxide emissions.

As mentioned in the literature review, previous studies applied to the G7 economies did not all validate an inverted *EKC*. On the other hand, there is also a gap in the literature regarding the testing of the *EKC* hypothesis in studies that have used the relationship between the human development index and carbon dioxide emissions. Therefore, considering this equation as associated with *EKC* is a differentiating factor in our investigation compared to others.

Next, we present the empirical analysis and results found for this research.

4. Results

This section presents the empirical results of this research. The general model tests the effects of the human development index (*HDI*), renewable energy (*REW*), foreign direct investment (*FDI*), openness to trade (*TRADE*), and carbon dioxide emissions. In the first step, we discuss the descriptive statistics, the unit root test, and the multicollinearity of the variables used in this research. In addition, we consider the cross-section dependence tests and second-generation unit root tests. These preliminary tests allow us to observe the properties of the variables used in this investigation and whether it is possible to move forward with the specification of econometric models.

Next, we test panel cointegration, and the Hausman test to decide between random effects, fixed effects estimator, and generalised linear model (Gamma estimator). Moreover, we used the panel fully modified ordinary least squares (FMOLS), panel dynamic ordinary least squares (DOLS), and panel ARDL model in this investigation. In addition to the general equation, we will present a discussion in Section 5 on the test of the *EKC* hypothesis through panel quantile regressions, which allows us to evaluate the hypothesis using different moments in different quartiles.

Figure 2 shows the distribution of carbon dioxide emissions for the G7 countries. The USA, Japan, and Germany are the countries in this sample with the highest levels of

polluting emissions. We can also mention that the United Kingdom, Italy, and Canada show a decreasing trend in carbon dioxide emissions.

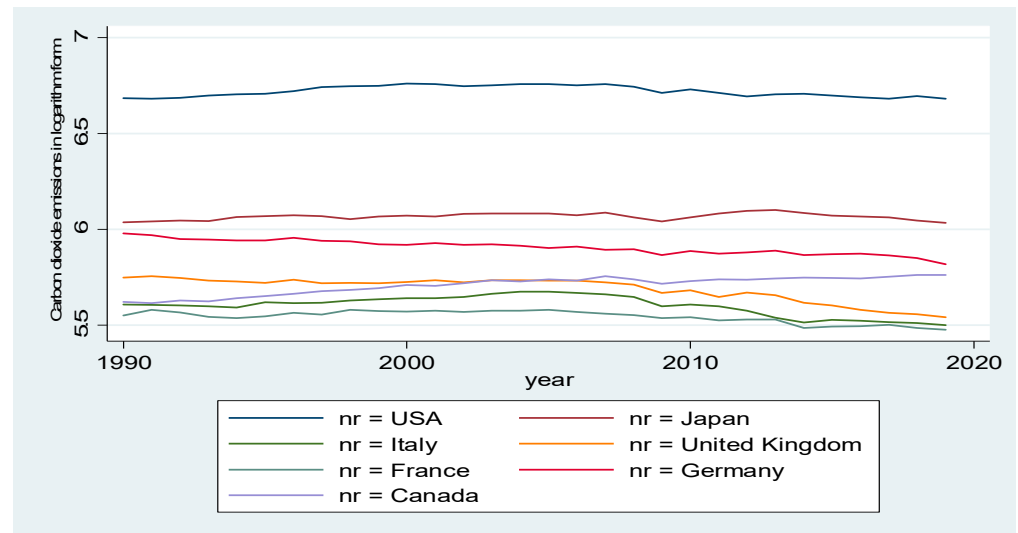


Figure 2. Carbon dioxide emissions in logarithm form.

Figure 3 evaluates the distribution of the human development index (*HDI*). The countries with the highest performance are Germany, the United Kingdom (with particular emphasis from 2008 onwards), Japan, and Canada.

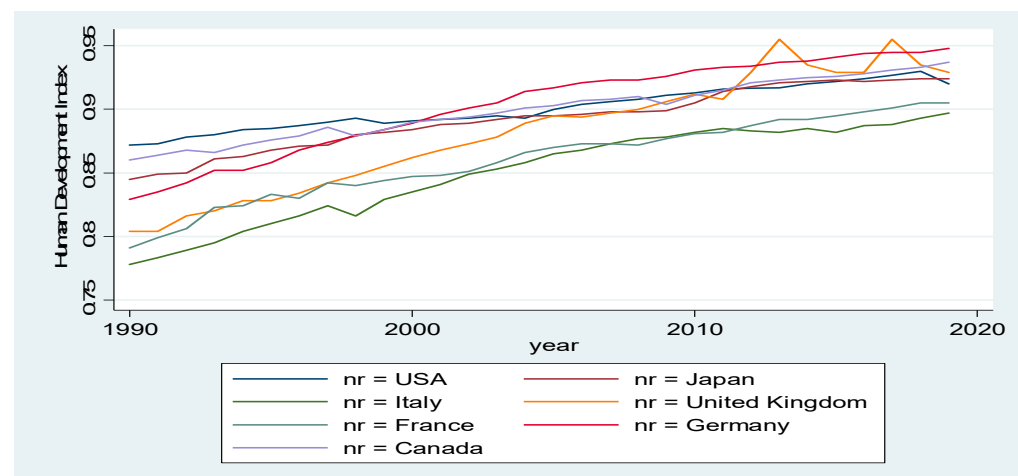


Figure 3. Human development index.

Then, we present the descriptive statistics and the correlations between the variables used in this research. The statistics of mean, median, maximum, and minimum values, standard deviations, skewness, and Kurtosis for the variables used in this research are presented in Table 1.

Table 1. General statistics.

Statistics	LogCO ₂	HDI	LogTRADE	LogREW	LogFDI
Mean	5.892	0.884	11.803	0.767	0.028
Median	5.736	0.888	11.796	0.840	0.187
Maximum	6.762	0.955	12.404	1.356	1.105
Minimum	5.478	0.778	11.174	−0.216	−3.126
Std. Dev.	0.385	0.038	0.258	0.449	0.634
Skewness	1.279	−0.594	0.213	−0.561	−1.821
Kurtosis	3.419	2.926	2.903	2.282	8.105
Prob.	0.000	0.002	0.447	0.000	0.000
Observations	203	203	203	203	203

Note: The variables are presented in logarithmic form with the exception of the human development index (HDI).

Table 1 shows that international trade (*LogTRADE*) and pollution emissions (*LogCO₂*—carbon dioxide emissions) variables offer higher values of maximum statistics. We kept all variables under and give positive values for Kurtosis for the model. Regarding the skewness, it is possible to see that the human development index (*HDI*), renewable energy (*LogREW*), and foreign direct investment (*LogFDI*) present a negative skewness, i.e., only the variables of carbon dioxide emissions (*LogCO₂*) and international trade (*LogTRADE*) have a positive skewness statistic.

The correlations between the variables under study can be seen in Table 2. The human development index (*HDI*) positively correlates with carbon dioxide emissions. The variable of renewable energy (*LogREW*) negatively correlates with CO₂ emissions. In addition, we observe that international trade (*LogTRADE*) positively correlates with carbon dioxide emissions.

Table 2. Correlations between variables.

Statistics	LogCO ₂	HDI	LogREW	LogTRADE	LogFDI
LogCO ₂	1.000				
HDI	0.288	1.000			
LogREW	−0.502	0.310	1.000		
LogTRADE	0.514	0.669	−0.013	1.000	
LogFDI	−0.099	0.186	0.061	0.093	1.000

Subsequently, regarding foreign direct investment (*FDI*), the empirical models defend either a positive signal (pollution haven hypothesis) or a negative signal (halo pollution), and we observe a negative correlation between *FDI* and carbon dioxide emissions.

Table 3 presents the results for the unit roots of the variables carbon dioxide emissions (*LogCO₂*), human development index (*HDI*), renewable energy consumption (*LogREW*), and foreign direct investment (*LogFDI*). It is concluded that the variables are integrated into the first differences.

Table 3. First-generation unit root test.

Variables	Level	First Difference
	Im, Pesaran, and Shin W-Stat	Im, Pesaran, and Shin W-Stat
LogCO ₂	2.700 (0.996)	−6.043 *** (0.000)
HDI	−2.133 ** (0.016)	−5.764 *** (0.000)
LogREW	4.608 (1.000)	−4.467 *** (0.000)
LogTRADE	0.421 (0.663)	−8.390 *** (0.000)
LogFDI	−2.050 ** (0.020)	−8.093 *** (0.000)

Notes: In the table, the asterisks represent different levels of statistical significance. ***—1% level, **—5% level.

However, the test presented in Table 3 is a first-generation unit root test, and it is then necessary to apply the multicollinearity test to understand whether the first-generation

unit root test is valid. Therefore, if multicollinearity exists between the variables used in this research, the second-generation unit root test must be carried out.

Next, we present the multicollinearity and cointegration test for all variables and the cross-dependency test to see if it is necessary to carry out second-generation unit root tests before proceeding with the estimations of the specified model.

Table 4 demonstrates the results of the multicollinearity test for the variables considered in this study, and it is observed that there are no multicollinearity problems between carbon dioxide emissions (dependent variable), and the explanatory variables (*HDI*—human development index, renewable energy—*LogREW*, openness to trade—*LogTRADE*, and foreign direct investment—*LogFDI*).

Table 4. VIF test.

Variables	VIF	1/VIF
<i>HDI</i>	2.28	0.44
<i>LogREW</i>	1.23	0.82
<i>LogTRADE</i>	2.01	0.50
<i>LogFDI</i>	1.04	0.96
Mean VIF	1.64	

Pedroni’s test [48] demonstrates cointegration between the variables through the Phillips–Perron group statistic in Table 5.

Table 5. Pedroni test.

	Statistic	Prob.
Group rho-Statistic	1.098	0.864
Group PP-Statistic	−3.242 ***	0.010
Group ADF-Statistic	0.026	0.510

Notes: In the table, the asterisks represent levels of statistical significance. ***—1% level.

In Table 6, we perform the cross-section dependence test, applying the Pesaran [49] criterion. Based on the results shown in Table 6, we observe that the variables used in this research have cross-dependence between them. Then, it is necessary to apply the second-generation test of the unit root test.

Table 6. Cross-section test.

Variables	CD-Test
<i>LogCO₂</i>	7.474 *** (0.000)
<i>HDI</i>	12.142 *** (0.000)
<i>LogREW</i>	19.519 *** (0.000)
<i>LogTRADE</i>	24.516 *** (0.000)
<i>LogFDI</i>	8.106 *** (0.000)

Notes: In the table, the asterisks represent levels of statistical significance. ***—1% level.

Considering the results showed in Table 6, it is necessary to use the Pesaran (CIPS test) to observe whether the variables used in this study are stationary.

In Table 7, the unit root test is presented, taking into account two criteria: the constant and the constant and trend. According to Table 7, the variables present stationarity with the second-generation criterion.

Table 7. CIPS test.

Variables	Constant	Lags	Constant and Trend	Lags
<i>LogCO₂</i>	−2.270 *	3	−2.900 ***	4
<i>HDI</i>	−2.239 *	5	−2.793 *	5
<i>LogREW</i>	−0.893	4	−2.778 **	4
<i>LogTRADE</i>	−3.057 ***	1	−2.799 **	2
<i>LogFDI</i>	−3.648 ***	0	−4.032 ***	0

Notes: In the table, asterisks represent different levels of statistical significance. ***—1% level; **—5% level, *—10% level.

The model is presented in Table 8 through the fixed effects (FE) and random effects (RE) estimators and the generalised linear model (GLM) via the Gamma model. According to the Hausman test, the random effect estimator must read and interpret the results. However, we can observe that the results with FE and RE are very similar.

Table 8. Testing environmental quality in G7 economies with panel data.

Independent Variables	Random Effects	Fixed Effects	Gamma
<i>HDI</i>	−0.860 *** (0.000)	−0.861 *** (0.000)	−0.075 *** (0.000)
<i>LogREW</i>	−0.141 *** (0.000)	−0.1402 *** (0.000)	0.014 *** (0.000)
<i>LogTRADE</i>	0.223 *** (0.000)	0.222 *** (0.000)	−0.015 *** (0.000)
<i>LogFDI</i>	0.013 *** (0.004)	0.012 ** (0.003)	0.002 *** (0.000)
C	4.123 *** (0.000)	4.136 *** (0.000)	0.409 *** (0.000)
Adj. R ²	0.60	0.62	
Observations	203	203	203
Hausman test	Chi2 (4) = 5.246 (0.263)		

Notes: In the table, the asterisks represent the levels of statistical significance. ***—1% level, **—5% level.

The coefficient of the human development index (*HDI*) has statistical significance at 1% by the three estimators. This result shows that human development aims to decrease climate change and stimulate sustainable development. The studies of Bezić et al. [23], Akbar et al. [25], and Opoku et al. [26] support our results.

As in previous studies (e.g., Gyamfi et al. [7]; Khan et al. [31]; Dogan et al. [33]; Chu and Le [46]), renewable energies (*LogREW*) improve the environment and reduce carbon dioxide emissions. Considering the random effects estimator, the variable of renewable energy (*LogREW*) presents a negative impact on carbon dioxide emissions with statistical significance at the 1% level. However, the Gamma model obtains the opposite expected sign.

Furthermore, international trade (*LogTRADE*) and foreign direct investment (*LogFDI*) positively impact carbon dioxide emissions, showing that these variables accentuate climate change. The pollution haven hypothesis explain these results. Nevertheless, according to the Gamma model, we observe that international trade (*LogTRADE*) negatively correlates with carbon dioxide emissions, showing that, in this case, openness to trade promotes sustainable development.

Table 9 shows the results obtained through the FMOLS and DOLS models. Considering the estimates obtained by the FMOLS model, it can be inferred that the human development index (*HDI*) negatively correlates with carbon dioxide emissions, demonstrating that human development reduces climate change and improves air quality.

This result has support from previous studies such as those of Bezić et al. [23], Sezgin et al. [24], Opoku et al. [26], and Majewska and Gierałtowska [45].

Table 9. Testing environmental quality in G7 economies with panel data.

Independent Variables	FMOLS	DOLS
<i>HDI</i>	−1.026 *** (0.000)	0.882 *** (0.001)
<i>LogREW</i>	−0.135 *** (0.000)	−0.156 *** (0.000)
<i>LogTRADE</i>	0.236 *** (0.000)	0.266 *** (0.000)
<i>LogFDI</i>	0.018 ** (0.015)	0.032 *** (0.000)
Observations	189	164

Notes: In the table, the asterisks represent the levels of statistical significance. ***—1% level, **—5% level.

The variable of renewable energy (*LogREW*) continues to demonstrate that it contributes to a decrease in carbon dioxide emissions. Moreover, the coefficient of renewable energies (*LogREW*) negatively impacts carbon dioxide emissions, indicating that cleaner energies can improve the environment, i.e., the carbon dioxide emissions decrease (−0.14%). The empirical studies of Apergis et al. [11], Szetela et al. [12], Acheampong et al. [13], Chen et al. [14], Raihan [15], and Hasanov et al. [16] give support to our results.

The results above show that the coefficients of international trade (*LogTRADE*) and foreign direct investment (*LogFDI*) positively impact polluting emissions.

The studies of Apergis et al. [11], Kayani et al. [41], and Wencong et al. [42] found a positive association between foreign direct investment and carbon dioxide emissions.

Following recent studies by Saqib et al. [1], Apergis [11], Dogan et al. [33], and Chu and Le [46] applied to the study of the G7 economies, it is observed that the studies used the methodology of Dumitrescu and Hurlin [50] to test panel causality under study (unidirectional versus bidirectional). Therefore, the Table 10 shows only the unidirectional and bidirectional relationships between the variables under study.

Table 10. Testing environmental quality in G7 economies: pairwise Dumitrescu–Hurlin panel causality.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
<i>HDI</i> does not homogeneously cause <i>LogCO₂</i>	3.958 ***	1.9400	(0.052)
<i>LogREW</i> does not homogeneously cause <i>LogCO₂</i>	7.865 ***	6.229	(0.000)
<i>LogCO₂</i> does not homogeneously cause <i>LogREW</i>	7.271 ***	5.577	(0.000)
<i>LogTRADE</i> does not homogeneously cause <i>LogCO₂</i>	4.8102 ***	2.876	(0.004)
<i>HDI</i> does not homogeneously cause <i>LogREW</i>	9.944 ***	8.511	(0.000)
<i>HDI</i> does not homogeneously cause <i>LogTRADE</i>	4.408 **	2.434	(0.015)
<i>LogTRADE</i> does not homogeneously cause <i>LogREW</i>	6.627 **	4.8707	(0.000)
<i>LogREW</i> does not homogeneously cause <i>LogTRADE</i>	4.1483 **	2.1493	(0.031)

Notes: In the table, asterisks represent different levels of statistical significance. ***—1% level, **—5% level.

There is a bidirectional relationship between renewable energies (*LogREW*) and carbon dioxide emissions (*LogCO₂*), and a bidirectional relationship between renewable energies (*LogREW*) and international trade (*LogTRADE*) is also observed.

Furthermore, the human development index (*HDI*), and carbon dioxide emissions (*LogCO₂*) shows a unidirectional relationship. There is also a unidirectional relationship between the human development index (*HDI*) and international trade (*LogTRADE*), and renewable energies (*LogREW*).

Next, we show the results using the pooled mean group (PMG) estimator, i.e., the panel ARDL model (autoregressive distributed lag), to observe if there are differences between the estimates and trends presented previously and the panel ARDL model. This estimator has the advantage of evaluating the impacts of explanatory variables on carbon dioxide emissions in the short and long run.

The results found in the short term are similar to those shown in previous estimates, except for the human development index (*HDI*), which does not have any statistical significance.

Thus, it is possible to conclude about the long-run results. According to the panel ARDL model shown in Table 11, it is observed that the *HDI* coefficient has statistical significance at 1%, demonstrating that it does not contribute to the reduction of carbon dioxide emissions. However, the coefficients of trade intensity (*LogTRADE*) and foreign direct investment (*LogFDI*) have a negative effect on carbon dioxide emissions with statistical significance at 1%, revealing that these variables allow for improving air and environmental quality. These results can be interpreted by the halo pollution hypothesis theory, which considers that international trade and *FDI* are associated with sustainable practices, innovation, and product differentiation via quality factors.

Table 11. Testing environmental quality in G7 economies with the PMG–ARDL model.

Independent Variables	Coefficient	Std. Error	<i>t</i> -Statistic	<i>p</i> -Value
Long Run Equation				
<i>HDI</i>	1.548 ***	0.317	4.877	(0.000)
<i>LogREW</i>	−0150 ***	0.024	−6.233	(0.000)
<i>LogTRADE</i>	−0.129 ***	0.047	−2.760	(0.004)
<i>LogFDI</i>	−0.027 ***	0.005	−4.521	(0.000)
Short Run Equation				
ECT	−0.096 ***	0.089	−1.079	(0.000)
Δ (<i>HDI</i>)	0.187	0.299	0.627	(0.531)
Δ (<i>LogREW</i>)	−0.099 *	0.055	−1.810	(0.072)
Δ (<i>LogTRADE</i>)	0.106 ***	0.022	4.848	(0.000)
Δ (<i>LogFDI</i>)	0.009 ***	0.003	2.911	(0.004)
C	0.613 ***	0.552	1.110	(0.268)
Mean dependent var	−0.002	S.D. dependent var		0.0137
S.E. of regression	0.011	Akaike info criteria		−5.678
Sum squared resid	0.017	Schwarz criteria		−4.927
Wald test = 4.878 (0.000) ***				

Notes: In the table, the asterisks represent the levels of statistical significance. ***—1% level, *—10% level.

Long-term analysis shows that the coefficients of international trade (*LogTRADE*), foreign direct investment (*LogFDI*), and renewable energy (*LogREW*) allow for a very significant environmental improvement in the G7 economies for the period in question. Thus, renewable energy (*LogREW*) contributes to a reduction in pollution by −0.150% and international trade (*LogTRADE*) and foreign direct investment (*LogFDI*) by −0.129% and −0.027%, respectively. In this context, such results can be explained by the fact that this group of countries are among the most developed economies in the world economy, and they have a high human development index, revealing signs of concern with environmental and sustainability issues.

Subsequently, we present a new section where we seek to discuss the results of this investigation. Furthermore, it evaluates and tests the environmental Kuznets curve using the human development index (*HDI*) and the squared human development index (*HDI*²), which has some degree of innovation compared to previous studies presented in the literature. In other words, previous empirical studies have only used the relationship between *HDI* and CO₂ emissions.

5. Discussion

In this section, we present and discuss the econometric results found in the empirical study. The empirical study began with tests of the properties of the variables used in this research, namely with the tests of first-generation unit roots. Next, multicollinearity and cointegration of the variables under study were evaluated. Once the cross-dependence between the variables used in this research was verified, it was necessary to carry out the second-generation unit root test. Since the variables are stationary, considering the second-generation unit root test, it was possible to estimate the econometric model through

fixed effects and random effects and the GLM (generalized linear model via Gamma model). The Hausman test demonstrated that reading results through random effects is preferable. Furthermore, the panel cointegration model (FMOLS and DOLS) and panel causality were applied to understand whether causality existed between the variables used in this research.

In an attempt to understand whether there is the same trend between the independent variables used and carbon dioxide emissions (dependent variable), the pooled mean group (PMG)–ARDL model was used, and this estimator allows, as was said previously, evaluation of the short- and long-term effects. In this context, econometric models demonstrate that the human development index (*HDI*) makes it possible to reduce climate change and improve the environment using fixed effects, random effects, and the Gamma model. However, the use of PMG demonstrates that this trend does not occur. However, the results find similarities between the different estimators used for the impacts of renewable energy. As in previous studies (Gyamfi et al. [7]; Khan et al. [31]; Dogan et al. [33]; Chu and Le [46]), renewable energy has been shown to contribute to environmental improvement. Openness to trade variables and foreign direct investment appear to reduce pollution levels when the ARDL model is applied, explaining the halo pollution hypothesis.

Another essential issue is understanding if the environmental Kuznets curve (*EKC*) is valid between the human development index and carbon dioxide emissions in G7 economies. The panel quantile regression, which evaluates the regressions at various moments for different quartiles, was used for this. Then, the results obtained for the *EKC* hypothesis can be observed through the panel quantile regressions in Table 12.

Table 12. Testing *EKC* using the human development index (*HDI*) in G7 economies.

	Quantile	Coefficient	Std. Error	<i>t</i> -Statistic	Prob.
<i>HDI</i>	0.10	12.642 ***	0.383	33.005	(0.000)
	0.20	12.637 ***	0.487	25.955	(0.000)
	0.30	10.257 ***	0.555	18.461	(0.000)
	0.40	10.102 ***	0.445	22.697	(0.000)
	0.50	10.088 ***	0.382	26.429	(0.000)
	0.60	10.489 ***	0.375	27.966	(0.000)
	0.70	10.525 ***	0.456	23.087	(0.000)
	0.80	9.779 ***	0.772	12.676	(0.000)
	0.90	8.534 ***	1.2628	6.758	(0.000)
<i>HDI</i> ²	0.10	−6.949 ***	0.456	−15.234	(0.000)
	0.20	−6.9107 ***	0.5807	−11.899	(0.000)
	0.30	−3.971 ***	0.717	−5.535	(0.000)
	0.40	−3.574 ***	0.567	−6.303	(0.000)
	0.50	−3.347 ***	0.478	−6.999	(0.000)
	0.60	−3.667 ***	0.455	−8.064	(0.000)
	0.70	−3.496 ***	0.521	−6.716	(0.000)
	0.80	−2.506 ***	0.884	−2.835	(0.005)
	0.90	−1.021	1.437	−0.711	(0.478)
<i>LogREW</i>	0.10	−0.188 ***	0.034	−5.488	(0.000)
	0.20	−0.188 ***	0.044	−4.321	(0.000)
	0.30	−0.273 ***	0.082	−3.353	(0.001)
	0.40	−0.409 ***	0.111	−3.701	(0.000)
	0.50	−0.547 ***	0.095	−5.777	(0.000)
	0.60	−0.605 ***	0.096	−6.300	(0.000)
	0.70	−0.734 ***	0.052	−14.239	(0.000)
	0.80	−0.769 ***	0.030	−25.671	(0.000)
	0.90	−0.716 ***	0.060	−11.934	(0.000)

Notes: In the table, the asterisks represent the levels of statistical significance. ***—1% level.

The human development index (*HDI*), squared human development index (*HDI*²), and renewable energy (*LogREW*) were used as independent variables, and the carbon dioxide emissions were the dependent variable. The analysis was carried out over the

different quartiles from 10% to 90%. Thus, for the human development index (*HDI*) and squared human development index, according to the literature and the assumptions of the *EKC*, a positive correlation is expected between the *HDI* and carbon dioxide emissions and a negative correlation with the squared human development index (HDI^2), showing an inverted curve of environmental Kuznets curve.

As seen in Table 12, the results are based on theoretical predictions, which means that the squared human development index (HDI^2) makes it possible to reduce polluting emissions in the long term. The coefficients of the human development index (*HDI*) and the squared human development index have statistical significance at 1%, except for the 90% quartile for the HDI^2 variable. The results demonstrate an inverted environmental Kuznets curve between the human development index and pollution emissions. For a more in-depth analysis of the topic, see, for example, the articles by Leal and Marques [51], and Sun et al. [52], where all types of *EKC* are discussed.

Regarding the renewable energy coefficient (*LogREW*), we observe a negative effect advanced in the literature. Throughout the different quartiles, the variable presents statistical significance at 1%. In the equation presented in Table 12 of this research, renewable energy can reduce greenhouse gas emissions.

After observing the econometric results (Section 4) and the Discussion section of the results found in this research, this study's conclusions are presented, emphasising the economic policy recommendations.

6. Conclusions

This investigation evaluates the impact of the human development index (*HDI*) on carbon dioxide emissions for the G7 group of countries (United States of America, Germany, Canada, Japan, Italy, the United Kingdom, and France) from 1990 to 2019. In addition, this research also considered the effects of renewable energies, foreign direct investment, and openness to trade on air quality via carbon dioxide emissions.

The choice of the human development index is based on an indicator involving life expectancy, education, and the GINI index; these components cover different areas of society and how society interacts with the economy.

The links between environmental policy, openness to trade, and foreign direct investment also support this research.

In relation to previous studies on the G7 economies, our study advances not only with a general equation that evaluates the impact of *HDI* on carbon dioxide emissions but also tests the validity of the environmental Kuznets curve hypothesis inverted with the use of panel quantile regressions, which allows validating the behaviour of the human development index and the squared human development index on carbon dioxide emissions over different moments for different quartiles.

In the previous section, Discussion, a summary of the procedures performed and the results found in the empirical study were highlighted. In summary terms, it can be stated that the fixed effects, random effects, Gamma model, and cointegration panel estimators (FMOLS, DOLS) demonstrate that foreign direct investment (*FDI*) and internationalisation process from home country to host country is explained considering the arguments of the Heckscher–Ohlin theorem. In addition, the results of international trade are presented by the revealed comparative advantages and pollution haven hypothesis (*PHH*). However, when using the PMG–panel ARDL model, it is observed that international trade and *FDI* are associated with sustainable and clean energy practices, appearing to contribute to sustainable development and the improvement of the environment.

It should be noted that the econometric results obtained are in line with international conferences, namely the Kyoto Protocol [53], Paris Agreement [54], Directive 2009/28/EC [55] or, more recently, the objectives established by the United Nations about sustainability (Sustainable Development Goals—Agenda 2030).

Next, we present some topics that should be introduced in future investigations and policy recommendations since our study has limitations like any other.

In future studies, the sample should be extended to another group of countries, such as the EU-27 and the BRICS, emphasising other indicators such as economic complexity, corruption, human capital, and green finance. The theories of international trade, but also the assumptions of the environmental Kuznets curve (EKC), which explains the different stages of development of economies, as well as the relationship between the pollution haven hypothesis and halo pollution hypothesis, should be considered in this type of study. In this context, following the recent contribution by Sun et al. [52], it will be interesting to delve deeper into the interdependent relationships between renewable energies, growth and air quality, and issues of structural adjustment with a view to environmental quality.

Another possible area of research for future work is understanding the impact of sustainable digital finance on polluting industries (e.g., Li et al. [56]) and the extent to which technological innovation can stimulate sustainable development. Moreover, the effect of commercial and industrial policy through patents and its association with sustainability and green innovation on the effects of pollution can be a new issue of study, as demonstrated by the recent study by Xu et al. [57].

Regarding the recommendations for economic policy, our research demonstrates that the human development index decreased carbon dioxide emissions in the long term, demonstrating that at a more advanced stage, countries pay more attention to environmental issues and, more specifically, to air quality. As mentioned, the human development index (HDI) has an advantage over per capita income (GDP) since the HDI assesses the components of life expectancy, education, and the distribution of wealth or inequality. From this, we conclude that studies must use the human development index instead of per capita income since this combines several dimensions.

Furthermore, the use of renewable energies improves the environment, and this result is in line with the most recent studies on the G7 economies. In this context, governments should continue to promote public policies that support using alternative and cleaner energy to achieve the sustainable development defined in the United Nations 2030 Agenda.

Hence, industrial policy measures should be used to promote international trade and investment flows associated with cleaner industries, where product differentiation will have to be based on the quality–price relationship via monopolistic competition. This measure will be essential to achieve the concept of green finance, thus contributing to sustainable development and environmental improvement.

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References

1. Saqib, N.; Sharif, A.; Razzaq, A.; Usman, M. Integration of renewable energy and technological innovation in realizing environmental sustainability: The role of human capital in EKC framework. *Environ. Sci. Pollut. Res.* **2023**, *30*, 16372–16385. [\[CrossRef\]](#)
2. Liu, P.-Z.; Narayan, S.; Ren, Y.-S.; Jiang, Y.; Baltas, K.; Sharp, B. Re-Examining the Income–CO₂ Emissions Nexus Using the New Kink Regression Model: Does the Kuznets Curve Exist in G7 Countries? *Sustainability* **2022**, *14*, 3955. [\[CrossRef\]](#)
3. Katircioglu, S. Estimating the role of urban development in environment quality: Evidence from G7 countries. *Energy Environ.* **2022**, *33*, 283–314. [\[CrossRef\]](#)
4. Isik, C.; Ahmad, M.; Pata, U.K.; Ongan, S.; Radulescu, M.; Adedoyin, F.F.; Bayraktaroglu, E.; Aydın, S.; Ongan, A. An Evaluation of the Tourism-Induced Environmental Kuznets Curve (T-EKC) Hypothesis: Evidence from G7 Countries. *Sustainability* **2020**, *12*, 9150. [\[CrossRef\]](#)
5. Mahmoodi, M.; Dahmardeh, N. Environmental Kuznets Curve Hypothesis with Considering Ecological Footprint and Governance Quality: Evidence from Emerging Countries. *Front. Environ. Sci.* **2022**, *10*, 849676. [\[CrossRef\]](#)
6. Leitão, N.C.; Koengkan, M.; Fuinhas, J.A. The Role of Intra-Industry Trade, Foreign Direct Investment, and Renewable Energy on Portuguese Carbon Dioxide Emissions. *Sustainability* **2022**, *14*, 15131. [\[CrossRef\]](#)

7. Gyamfi, A.B.; Ampomah, A.B.; Bekun, F.V.; Asongu, S.A. Can information and communication technology and institutional quality help mitigate climate change in E7 economies? An environmental Kuznets curve extension. *J. Econ. Struct.* **2021**, *11*, 14. [\[CrossRef\]](#)
8. Cole, M.A. Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecol. Econ.* **2004**, *48*, 71–81. [\[CrossRef\]](#)
9. Leitão, N.C. Testing the Role of Trade on Carbon Dioxide Emissions in Portugal. *Economies* **2021**, *9*, 22. [\[CrossRef\]](#)
10. Leitão, N.C.; Dos Santos Parente, C.C.; Balsalobre-Lorente, D.; Cantos Cantos, J.M. Revisiting the effects of energy, population, foreign direct investment, and economic growth in Visegrad countries under the EKC scheme. *Environ. Sci. Pollut. Res. Int.* **2023**, *30*, 15102–15114. [\[CrossRef\]](#)
11. Apergis, N.; Kuziboev, B.; Abdullaev, I.; Rajabov, A. Investigating the association among CO₂ emissions, renewable and non-renewable energy consumption in Uzbekistan: An ARDL approach. *Environ. Sci. Pollut. Res. Int.* **2023**, *30*, 39666–39679. [\[CrossRef\]](#)
12. Szetela, B.; Majewska, A.; Jamroz, P.; Djalilov, B.; Salahodjaev, R. Renewable Energy and CO₂ Emissions in Top Natural Resource Rents Depending Countries: The Role of Governance. *Front. Energy Res.* **2022**, *10*, 872941. [\[CrossRef\]](#)
13. Acheampong, A.O.; Dzator, J.; Savage, D.A. Renewable Energy, CO₂ Emissions and Economic Growth in Sub-saharan Africa: Does Institutional Quality Matter? *J. Policy Model.* **2021**, *45*, 1070–1093. [\[CrossRef\]](#)
14. Chen, C.; Pinar, M.; Stengos, T. Renewable energy and CO₂ emissions: New evidence with the panel threshold model. *Renew. Energy* **2022**, *194*, 117–128. [\[CrossRef\]](#)
15. Raihan, A. The Dynamic Nexus between Economic Growth, Renewable Energy Use, Urbanization, Industrialization, Tourism, Agricultural Productivity, Forest Area, and Carbon Dioxide Emissions in the Philippines. *Energy Nexus* **2023**, *9*, 100189. [\[CrossRef\]](#)
16. Hasanov, F.J.; Mukhtarov, S.; Suleymanov, E. The Role of Renewable Energy and Total Factor Productivity in Reducing CO₂ Emissions in Azerbaijan. Fresh Insights from a New Theoretical Framework Coupled with Autometrics. *Energy Strat. Rev.* **2023**, *47*, 101079. [\[CrossRef\]](#)
17. Grossman, G.M.; Krueger, A.B. Economic growth and the Environment. *Q. J. Econ.* **1995**, *110*, 353–377. [\[CrossRef\]](#)
18. Pata, U.K.; Dam, M.M.; Kaya, F. How Effective are Renewable Energy, Tourism, Trade Openness, and Foreign Direct Investment on CO₂ Emissions? An EKC analysis for ASEAN countries. *Environ. Sci. Pollut. Res.* **2023**, *30*, 14821–14837. [\[CrossRef\]](#) [\[PubMed\]](#)
19. Fuinhas, J.A.; Koengkan, M.; Leitão, N.C.; Nwani, C.; Uzuner, G.; Dehdar, F.; Relva, S.; Peyerl, D. Effect of Battery Electric Vehicles on Greenhouse Gas Emissions in 29 European Union Countries. *Sustainability* **2021**, *13*, 13611. [\[CrossRef\]](#)
20. Balogh, J.M. The impacts of agricultural development and trade on CO₂ emissions? Evidence from the Non-European Union countries. *Environ. Sci. Policy* **2022**, *137*, 99–108. [\[CrossRef\]](#)
21. Kostakis, I.; Konstadinos, S.A.; Theodoropoulou, A.E. The Investigation of EKC within CO₂ emissions Framework: Empirical Evidence from Selected Cross-Related Countries. *Sustain. Anal. Model.* **2023**, *3*, 100015. [\[CrossRef\]](#)
22. Houran, M.A.; Mehmood, U. Defining the Roles of Socio-Economic Factors and Bureaucratic Quality to Minimize the Impacts of Fossil Fuels Consumption on CO₂ emissions in G-20 Countries. *Environ. Sci. Pollut. Res.* **2023**, *30*, 51440–51449. [\[CrossRef\]](#)
23. Bezić, H.; Mance, D.; Balaž, D. Panel Evidence from EU Countries on CO₂ Emission Indicators during the Fourth Industrial Revolution. *Sustainability* **2022**, *14*, 12554. [\[CrossRef\]](#)
24. Sezgin, F.H.; Bayar, Y.; Herta, L.; Gavriltea, M.D. Do Environmental Stringency Policies and Human Development Reduce CO₂ Emissions? Evidence from G7 and BRICS Economies. *Int. J. Environ. Res. Public Health* **2021**, *18*, 6727. [\[CrossRef\]](#)
25. Akbar, M.; Hussain, A.; Akbar, A.; Ullah, I. The Dynamic Association between Healthcare Spending, CO₂ Emissions, and Human Development Index in OECD Countries: Evidence from Panel VAR Model. *Environ. Dev. Sustain.* **2021**, *23*, 10470–10489. [\[CrossRef\]](#)
26. Opoku, E.E.O.; Dogah, K.E.; Aluko, O.A. The Contribution of Human Development Towards Environmental Sustainability. *Energy Econ.* **2022**, *106*, 105782. [\[CrossRef\]](#)
27. Ike, G.N.; Usman, O.; Alola, A.A.; Sarkodie, S.A. Environmental Quality Effects of Income, Energy Prices and Trade: The Role of Renewable Energy Consumption in G-7 Countries. *Sci. Total Environ.* **2020**, *721*, 137813. [\[CrossRef\]](#)
28. Khalfaoui, R.; Kumar Tiwari, A.K.; Khalid, U.; Shahbaz, M. Nexus between Carbon Dioxide Emissions and Economic Growth in G7 countries: Fresh Insights Via Wavelet Coherence Analysis. *J. Environ. Plan. Manag.* **2023**, *66*, 31–66. [\[CrossRef\]](#)
29. Yilanci, V.; Ozgur, O. Testing the Environmental Kuznets Curve for G7 Countries: Evidence from a Bootstrap Panel Causality Test in Rolling Windows. *Environ. Sci. Pollut. Res.* **2019**, *26*, 24795–24805. [\[CrossRef\]](#)
30. Usman, K.; Bashir, U. The Causal Nexus between Imports and Economic Growth in China, India and G7 Countries: Granger Causality Analysis in the Frequency Domain. *Heliyon* **2022**, *8*, e10180. [\[CrossRef\]](#) [\[PubMed\]](#)
31. Khan, S.; Yahong, W.; Chandio, A.A. How does economic complexity affect ecological footprint in G-7 economies: The role of renewable and non-renewable energy consumptions and testing EKC hypothesis. *Environ. Sci. Pollut. Res.* **2022**, *29*, 47647–47660. [\[CrossRef\]](#)
32. Yilanci, V.; Pata, U.K. On the interaction between fiscal policy and CO₂ emissions in G7 countries: 1875–2016. *J. Environ. Econ. Policy* **2022**, *11*, 196–217. [\[CrossRef\]](#)
33. Dogan, B.; Chu, L.K.; Ghosh, S.; Truong, H.H.D.; Balsalobre-Lorente, D. How Environmental Taxes and Carbon Emissions are Related in the G7 Economies? *Renew. Energy* **2022**, *187*, 645–656. [\[CrossRef\]](#)
34. Roy, J. On the Environmental Consequences of Intraindustry Trade. *J. Environ. Econ. Manag.* **2017**, *83*, 50–67. [\[CrossRef\]](#)

35. Leitão, N.C.; Balogh, M.J. The Impact of Intra-Industry Trade on Carbon Dioxide Emissions: The Case of the European Union. *Agric. Econ.* **2020**, *66*, 203–214. [\[CrossRef\]](#)
36. Osabuohien-Irabor, O.; Drapkin, I.M. Toward Achieving Zero-Emissions in European Union Countries: The Contributions of Trade and Overseas Direct Investments in Consumption- Based Carbon Emissions. *AIMS Environ. Sci.* **2023**, *10*, 129–156. [\[CrossRef\]](#)
37. Yahya, F.; Lee, C.C. The Asymmetric Effect of Agriculturalization Toward Climate Neutrality Targets. *J. Environ. Manag.* **2023**, *328*, 116995. [\[CrossRef\]](#)
38. Thi, D.; Tran, V.Q.; Nguyen, D.T. The Relationship between Renewable Energy Consumption, International Tourism, Trade Openness, Innovation and Carbon Dioxide Emissions: International Evidence. *Int. J. Sustain. Energy* **2023**, *42*, 397–416. [\[CrossRef\]](#)
39. Rahaman, M.; Hossain, M.; Chen, S. The Impact of Foreign Direct Investment, Tourism, Electricity Consumption, and Economic Development on CO₂ emissions in Bangladesh. *Environ. Sci. Pollut. Res.* **2022**, *29*, 37344–37358. [\[CrossRef\]](#) [\[PubMed\]](#)
40. Balsalobre-Lorente, D.; Parente, C.C.S.; Leitão, N.C.; Cantos, C.J.M. The Influence of Economic Complexity Processes and Renewable Energy on CO₂ emissions of BRICS. What About Industry 4.0? *Resour. Policy* **2023**, *82*, 103547. [\[CrossRef\]](#)
41. Kayani, N.U.; Sadiq, M.; Aysan, A.F.; Haider, S.A.; Nasim, I. The Impact of Investment, Economic Growth, Renewable Energy, Urbanisation, and Tourism on Carbon Emissions: Global Evidence. *Int. J. Energy Econ. Policy* **2023**, *13*, 403–412. [\[CrossRef\]](#)
42. Wencong, L.; Kasimov, I.; Saydaliev, H.B. Foreign Direct Investment and Renewable Energy: Examining the Environmental Kuznets Curve in Resource-Rich Transition Economies. *Renew. Energy* **2023**, *28*, 301–310. [\[CrossRef\]](#)
43. Hussain, A.; Dey, S. Revisiting Environmental Kuznets Curve with HDI: New Evidence from Cross-Country Panel Data. *J. Environ. Econ. Policy* **2021**, *10*, 324–342. [\[CrossRef\]](#)
44. Romero, J.P.; Gramkow, C. Economic Complexity and Greenhouse Gas Emissions. *World Dev.* **2021**, *139*, 105317. [\[CrossRef\]](#)
45. Majewska, A.; Gierałtowska, U. Impact of Economic Affluence on CO₂ Emissions in CEE Countries. *Energies* **2022**, *15*, 322. [\[CrossRef\]](#)
46. Chu, L.K.; Le, N.T.M. Environmental Quality and the Role of Economic Policy Uncertainty, Economic Complexity, Renewable Energy, and Energy Intensity: The Case of G7 Countries. *Environ. Sci. Pollut. Res.* **2022**, *29*, 2866–2882. [\[CrossRef\]](#)
47. Ata, N.K.; Likhachev, V.L. Validation of the Environmental Kuznets Curve Hypothesis and Role of Carbon Emission Policies in the Case of Russian Federation. *Environ. Sci. Pollut. Res.* **2022**, *29*, 63407–63422.
48. Pedroni, P. Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors. *Oxf. Bull. Econ. Stat.* **1990**, *61*, 653–670. [\[CrossRef\]](#)
49. Pesaran, M.H. A Simple Panel Unit Root Test in the Presence of Cross-Section Dependence. *J. Appl. Econom.* **2007**, *22*, 265–312. [\[CrossRef\]](#)
50. Dumitrescu, E.I.; Hurlin, C. Testing for Granger non-Causality in Heterogeneous Panels. *Econ. Model.* **2012**, *29*, 1450–1460. [\[CrossRef\]](#)
51. Leal, P.H.; Marques, A.C. The Evolution of the Environmental Kuznets Curve Hypothesis Assessment: A Literature Review Under a Critical Analysis Perspective. *Heliyon* **2022**, *8*, e115221. [\[CrossRef\]](#) [\[PubMed\]](#)
52. Sun, A.; Bao, K.; Aslam, M.; Gu, X.; Khan, Z.; Uktamov, K.F. Testing Load Capacity and Environmental Kuznets Curve Hypothesis for China: Evidence from Novel Dynamic Autoregressive Distributed Lags Model. *Gondwana Res.* **2023**, *in press*. [\[CrossRef\]](#)
53. Kyoto Protocol to the United Nations Framework Convention on Climate Change. 1997, Kyoto 11 December. Available online: https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-7-a&chapter=27&clang=_en (accessed on 1 December 2023).
54. The Paris Agreement: What is the Paris Agreement, United Nations. Available online: <https://unfccc.int/process-and-meetings/the-paris-agreement> (accessed on 5 December 2023).
55. DIRECTIVE 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC. Available online: <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028> (accessed on 5 December 2023).
56. Li, J.; Zhang, G.; Ned, J.P.; Sui, L. How Does Digital Finance Affect Green Technology Innovation in the Polluting Industry? Based on the Serial Two-Mediator Model of Financing Constraints and Research and Development (R&D) Investments. *Environ. Sci. Pollut. Res.* **2023**, *30*, 74141–74152.
57. Xu, A.; Song, M.; Xu, S.; Wang, W. Accelerated Green Patent Examination and Innovation Benefits: An Analysis of Private Economic Value and Public Environmental Benefits. *Environ. Sci. Pollut. Res.* **2024**, *200*, 123105. [\[CrossRef\]](#)

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