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The Impact of Renewable Energy Consumption, Economic Growth, Globalization, and Financial Development on Carbon Dioxide Emissions: Evidence from Selected G7 Economies

Agbortoko Agbortoko Egbe [1], Oluwatoyin Abidemi Somoye [2,]* and Huseyin Ozdeser [2]

1 Department of Business Administration, Near East University, Nicosia 99138, Cyprus; 20233362@std.neu.edu.tr (A.A.E.)
2 Department of Economics, Near East University, Nicosia 99138, Cyprus; huseyin.ozdeser@neu.edu.tr (H.O.)

* Corresponding author. E-mail: abidemi.somoye@neu.edu.tr (O.A.S.)

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ABSTRACT: The aggregate upsurge in carbon dioxide emissions (CO_2) witnessed through environmental degradation and global climate change is a call for great concern. This, therefore, calls for the enactment, utilization and implementation of provisions and policies geared towards curbing this global economic bad without impeding global economic growth rates. This study ascertains the extent to which renewable energy consumption (REC), economic growth (GDP), population growth (POP), globalization (GLO), and financial development (FD) affect carbon dioxide emissions (CO_2) in selected G7 economies (France, Germany, Canada, Italy, and the United Kingdom) from 1990–2020. The Dynamic Fixed Effect Autoregressive Distributive Lag (DFE-ARDL) and the Pooled Mean Group ARDL (PMG-ARDL) methods were employed for analysis. The empirical findings for DFE-ARDL showed that REC, GDP, and POP have an adverse association with CO_2 in the long-term. However, in the short-term, REC and FD improve the environment, while GDP and POP drive CO_2. It is observed that the result for REC in the short and long-run is consistent. The PMG-ARDL results revealed that REC and GLO negatively affect CO_2 in the long-run, and in the short-run, GDP spurs CO_2, while FD reduces it. The result summary of both methods employed demonstrates that REC, GLO, and FD benefit the environment. At the same time, GDP and POP harm the environment in the short-run but reduce CO_2 in the long-run. Conclusively, the research recommends increasing the utilization of renewable energy and policies that enable economic growth and CO_2 to move in the opposite direction.

Keywords: Renewable energy; GDP; Globalization; Financial development; DFE-ARDL; PMG-ARDL

1. Introduction

In recent times, environmental degradation has increasingly gained popularity around the world. This increase is justified because conducive environmental conditions are fundamental for our livelihood. Further bolstering the relevance of the subject matter is confirmed by global warming, evidenced by climatic irregularities such as the decrease in snow level cover, rising temperatures, rising sea levels, droughts as well as the manifestation of storms [1]. The 2012 results published by the World Health Organization (WHO) estimated environmental pollution to be one of the world's greatest threats, given that its estimated causalities stood at about seven million [2]. The most significant of all aspects responsible for this degradation is the release of carbon dioxide emissions (CO_2) caused by human activities associated with non-renewable energy sources like fossil fuels.

It is essential to state that various social, economic, political, and cultural factors could reduce or accelerate CO_2. Some studies that have covered this broad scale of factors include [3–6]. Specifically, these factors include renewable energy consumption (REC), economic growth (GDP), population growth (POP), globalization (GLO), and financial development (FD).

Renewable energy is viewed as an important alternative for lowering CO_2 and improving environmental quality [7]. Renewable energy resources, such as hydropower, solar, and wind, do not emit greenhouse gases, as opposed to fossil fuels [8]. Therefore, expanding the use of clean energy technologies has the potential to cut dramatically CO_2

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from the power sector and other energy-intensive industries [9]. Conversely, the role of GDP in influencing CO_2 has been well-explained by [10], who stated that when an economy is just starting out in its developmental phase, more focus is on its growth rather than the quality of the environment. However, as the economy approaches a developed state, ecological progress is observed due to the adoption of new technologies and an enlightened population. Furthermore, globalization plays a crucial role in countries achieving their climate goals. Globalization means a country can interact with other countries through trade, culture, politics, and finance. It also involves the movement of people from one location to another. Globalization simply means a country's economy is linked with the global economy. Therefore, the economic interaction of a country with other countries will determine its environment, especially if the trade dynamics, politics, and financial dealings are examined. Lastly, a well-developed financial system can increase a country's economic efficiency [11]. The argument regarding the FD-CO_2 nexus comes in two folds: positive and negative. Firstly, the positive association can be observed through three channels, namely, direct, business, and wealth effects [12]. The *direct effect* is when consumers have access to finance (loans) due to lower rates, making them purchase energy-consuming products that can drive CO_2 upwards. The *business effect* relates to businesses expanding their capacity due to cheap access to financial capital, thus spurring CO_2. The *wealth effect* is when consumer and business confidence increases due to the wealth-creating ability of the stock market, which could increase energy demand and CO_2 [13,14]. Secondly, the negative link between FD and CO_2 occurs because firms and other energy stakeholders are motivated due to a developed financial system to embrace innovative technologies. This occurs by extensively investing in research and development (R&D) [15]. The inconsistencies in FD and CO_2 nexus necessitate further investigation.

Based on the G7 country classification, this article presents evidence from France, Germany, Canada, Italy, and the United Kingdom. These countries were selected because they are highly industrialized developed countries, have huge renewable energy potentials, and are among the largest groups of CO_2 emitters. In addition, these countries are economically advanced, and they further exert direct and indirect influences relative to the enactment of environmental and technological advancements and global policy implementation. Ref. [16] stated that G7 economies are responsible for 25% of energy system CO_2. The report further revealed that these economies could set the global standard for lowering emissions from heavy industries. Therefore, the information gleaned from these countries will contribute to robust policy formulation that can apply to other economies.

Objectively, this study examines the relationship between REC, GDP, POP, GLO, FD and CO_2 in selected G7 economies from 1990–2020 using methods such as the PMG-ARDL and DFE-ARDL. Therefore, the research questions can simply be stated: Does REC, GDP, POP, GLO and FD have a positive, a negative, or no association with CO_2? Depending on the results, what are some of the reasons for this outcome?

The present research's contribution to the existing literature can be witnessed from more than one perspective. To begin with, the study accentuates the importance and relevance of REC policies as a tool in the CO_2 reduction endeavors. Secondly, this study further outlines a host of other factors that when simultaneously applied with REC, enhance reduction in CO_2. Thirdly, this research's model (variables selected) is unique as it investigates the combined impact of REC, GDP, POP, GLO, and FD on CO_2, specifically in selected G7 economies—an area largely unexplored in existing studies. Fourthly, this research employs robust second-generation econometric methods such as the PMG-ARDL and DFE-ARDL, whose results account for scenarios relative to both static and dynamic eventualities. These methods are suitable because (i) They both capture the true essence of the dynamic relationship between the variables; (ii) They illustrate both the short and long-run estimation effects; (iii) They are characterized by efficiency and consistency in model estimation; (iv) They address heterogeneity-related issues in the model; (v) they are suitable for panel data analysis and most especially non-stationary data and; (vi) They establish clear and interpretable variable relationships.

2. Literature Review

2.1. REC and CO_2 Relationship

REC is a by-product of R&D and technological advancements. These include solar, wind, tidal, and hydroelectric energy sources. Ref. [17] studied how CO_2 in BRICS countries affects REC and technological progress. The outcomes suggest a negative relationship between both variables. Ref. [18] examined the extent to which REC, economic globalization, and GDP influence CO_2 in Turkey. Based on F-ARDL cointegration and the Fourier-Granger causality test, the empirical results illustrate an inverse relationship between REC and CO_2 and a positive relationship between GDP, economic GLO, and CO_2. Equally, the results show the existence of bidirectional causality linking economic GLO to CO_2 and GLO to REC.

Ref. [19] explored the effects of REC, GDP, FD, and the control of corruption on CO_2 in Asia Pacific Economic Cooperation economics. Using the PMG-ARDL technique, the findings show that high CO_2 significantly accelerates GDP and REC, whereas FD and control of corruption significantly account for low CO_2. Ref. [20] investigated the impact of REC and oil prices on CO_2 intensity in the Chinese transport sector. Based on the Bootstrap ARDL methodology, their findings indicate that oil price and REC reduces CO_2. Ref. [21] examined the effects of GDP, urbanization, trade openness, FD, and REC on CO_2 in Pakistan. The outcome of the fixed effect technique confirms that urbanization, FD, and trade openness significantly increase CO_2 while REC decreases CO_2. Utilizing the GMM method, ref. [22] established that technological innovation enhances the creation and development of REC, whose consumption records an inverse effect on CO_2 in BRICS economies.

Ref. [23] examined the dynamic linkages between CO_2, energy utilization, financial growth, and GDP in SAARC nations. Based on first and second-generation econometric approaches, the results show that energy consumption, FD, export of products, and economic expansion positively enhance CO_2. Using the quantile-on-quantile regression and Fixed Effect Ordinary Least Squares methods, ref. [24] argued that all variables are positively associated with REC. At the same time, FD and government stability positively impact CO_2 in GCC countries. Ref. [25] also found that REC benefits the environment in G7 economies. In Western and European economies, Ref. [26] opined that REC negatively links with CO_2.

2.2. GDP and CO_2 Relationship

Given the availability of different conclusions, the nexus between GDP and CO_2 remains inconclusive. Using the ARDL method, ref. [27] found that China's GDP and CO_2 are relatively decoupling. Evidence from the variance decomposition indicates that CO_2 will account for 20% of any shock to economic growth in the future [28]. Ref. [29] researched the links between Pakistan's energy consumption, GDP, and CO_2 using the ARDL technique. The findings showed that energy consumption and GDP drive CO_2. Ref. [30] investigated the impact of urbanization and GDP on CO_2 in SSA countries. With inference from the STIRPAT framework, the results showed that urbanization, GDP, industrial structure, trade, and POP, except for energy intensity, significantly influence CO_2. Ref. [31] examined the connection between natural resources, REC, GDP, and CO_2 subject to 35 BRICS economies using the OLS and GMM methods. The results showed CO_2 and REC as the driving factors of GDP, while natural resources reduce GDP. The results further illustrate that GDP and natural resources spur CO_2 while REC reduces it. Ref. [32] investigated the link between CO_2 and regional GDP based on the Environmental Kuznets Curve. Relative to the utilization of the mean decomposition method, the result indicates the existence of an inverse U-shaped relationship and the occurrence of a Kuznets curve between both variables. In addition, ref. [25] confirmed the EKC hypothesis in G7 countries.

2.3. POP and CO_2 Relationship

Population growth is closely associated with CO_2. Ref. [33] investigated the impact of REC, forestry, GDP, and demographics on the carbon footprint in India. Based on their analytical procedures, the empirical results show that GDP increases the carbon footprint in the short-run (SR) and long-run (LR), while the demographic variable had no influence. In addition, in East Asian countries, ref. [34] found that population aging significantly reduces CO_2, while energy generation, economic globalization, and GDP significantly and positively enhance CO_2. In China, Using the multiple mediation effect model, ref. [35] found that population aging reduces CO_2 emissions. Ref. [36] analyzed the nonlinear impact of POP agglomeration in big cities on CO_2. Their suggested results show that POP in big cities significantly raises CO_2 through channels associated with both transportation and industrial effects. Ref. [37] assessed the impact of POP factors and low-carbon innovation on CO_2 as evidenced by China. The results retrieved based on the PMG-ARDL approach argued that both POP size and density increase CO_2, while low-carbon innovation and POP quality in the LR decrease CO_2. Ref. [38] opined that energy consumption and GDP positively drive CO_2, while POP had little or no effect on CO_2 in Malaysia, Indonesia, and Thailand.

The significance and relevance of the concept of globalization cannot be undermined. This is a result of an ever-changing business environment, which is linked to the practice of sustainable endeavors [39]. Ref. [40] found that biomass energy significantly reduces CO_2 directly and indirectly. In addition, social and political GLO enhance biomass energy consumption in reducing CO_2. Ref. [41] analyzed the impact of inequality, GLO, and GDP on CO_2 in SSA countries using Driscoll-Kray and Generalized Least Square (GLS) regression models. The results suggest that GLO is environmentally friendly because it mitigates CO_2. Using the NARDL method, ref. [42] found that negative shocks in GLO and GDP influence CO_2 positively and negatively, respectively. POP also influences CO_2 positively. Using the Pooled Mean Group (PMG) estimator, ref. [43] revealed that institutional quality, REC, and GLO aid in the reduction of CO_2, while GDP and FD significantly enhance CO_2 for the OECD countries. Employing the fixed effect model, ref. [44] found that social globalization spurs CO_2 in 170 countries.

2.4. FD and CO_2 Relationship

Using the OLS, fixed effects, Dynamic Systems GMM, and GLS methods, ref. [45] found that GDP and FD drive CO_2 in Belt and Road economies. Utilizing the frequency domain and Fourier ARDL approach, ref. [46] revealed that FD exerts a positive and significant effect on CO_2. Employing the FMOLS estimator, ref. [47] opined that there is an adverse link between FD and CO_2 in G8 countries. Furthermore, ref. [48] assessed the impact of FD on CO_2 in Jamaica using the NARDL framework and found that FD negatively affects CO_2. Additionally, ref. [49], using the GMM approach examined the impact financial market development has on CO_2 in 83 countries. The results show a reduction in CO_2 for both emerging and developing countries as FD increases. Again, ref. [50] assessed the impact of FD on CO_2 and found that FD significantly increases CO_2 for emerging markets and developing countries, while for developed countries, FD exerts no effect on CO_2. In addition, ref. [51] investigated the extent to which CO_2 is influenced by FD mechanisms in China. The results indicate a drastic reduction in CO_2 by FD in the LR, accompanied by no significant short-term relationship. Ref. [52] investigated the dynamic linkages between FD, GLO, and CO_2 and found that FD and GLO significantly reduce CO_2, while GDP and energy intensity enhance CO_2. Ref. [53] examined the extent to which CO2 emissions in REC countries are influenced by GDP, REC, NRE, trade openness, and FD. The results show a negative link between REC, trade openness, FD, and CO_2. In G7 economies, ref. [54] established that FD contributes to environmental degradation.

The relationship between REC, GDP, POP, GLO, FD, and CO_2 has been subject to many complex and diversified conclusions. It is worth noting that many studies have examined this subject matter, but significant gaps still do occur, which is a basis for further research. The identified gaps in the existing literature are (i) inadequacies relative to multivariate analytical methods and procedures. As a result, the PMG-ARDL, and DFE-ARDL methods are employed; (ii) inadequate illustration of short and long-run estimation necessary for the policy evaluation; (iii) Inadequate literature on the degree to which CO_2 is enhanced by FD and GLO. Specifically, using the financial development and globalization indexes are some of the contributions of this research. In conclusion, the research, to a greater extent, attempts to overcome these gaps to provide more feasible, comprehensive, and reliable results for well-informed policy recommendations and decision-making.

3. Data and Methodology

3.1. Data

The analysis is comprised of data ranging from 1990 to 2020. CO_2 (Carbon dioxide emissions in metric tons) is the regressand, while its explanatory variables are REC (Renewable Energy Consumption), Economic Growth (GDP per capita constant US$2015), POP (Population growth rate), GLO (Globalization), and FD (Financial Development). CO_2, REC, and GDP are from the [55]; GLO data is from [56], and FD data is from [57]. The list of the variables can be seen in Table 1 and the graphical representation of the variables is presented in Figure 1.

Table 1. Variables description.

Symbol	Variable	Source
CO_2	Carbon dioxide emissions in metric tons	World Bank (2024)
REC	Renewable energy consumption (% of total final energy consumption)	World Bank (2024)
GDP	GDP Per Capita Constant US$2015	World Bank (2024)
POP	Population Growth (annual%)	World Bank (2024)
FD	Financial Development	IMF (2023)
GLO	Globalization	KOF Swiss Economic Institute (2024)

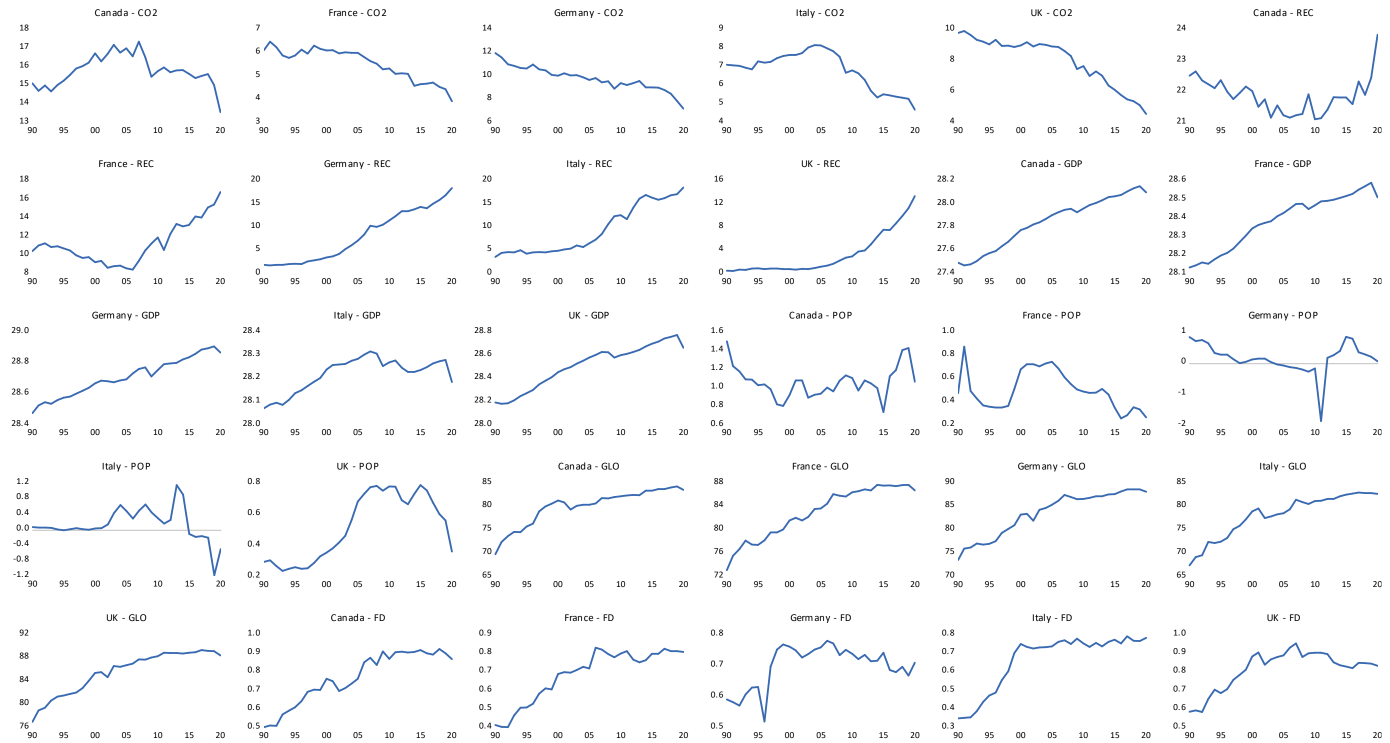

Figure 1. Variables plot.

Furthermore, this study model can be written as:

$$CO_{2it} = f\,(REC_{it}, GDP_{it}, POP_{it}, GLO_{it}, FD_{it}) \quad (1)$$

Equation (1) can be further written as:

$$CO_{2it} = \alpha + \beta_1 REC_{it} + \beta_2 GDP_{it} + \beta_3 POP_{it} + \beta_4 GLO_{it} + \beta_5 FD_{it} + \varepsilon_{it} \quad (2)$$

where: ε = Error Term; $\beta_1 - \beta_4$ = Coefficients of independent variables; α = Intercept; i = Countries and t = Time. In addition, based on the reviewed literature, we hypothesize that REC will be negatively associated with CO_2 emissions. In contrast, the impact of GDP, POP, GLO, and FD on CO_2 can be positive or negative.

3.2. Methodology

3.2.1. Pooled Mean Group ARDL (PMG-ARDL)

This study employs the PMG-ARDL method proposed by [58]. The model is utilized when the variables under analysis are stationary either at I(0) or I(1) or both but never at I(2). The reliability of this model is that it illustrates variable result analysis for the SR and LR. The merits attributed to this model are buttressed by its ability to outplay aspects relating to multicollinearity, autocorrelation, heteroscedasticity, and endogeneity-related issues. Three aspects, including the Pooled mean Group (PMG), Mean Group (MG), and Dynamic Fixed effects (DFE), constitute the aforementioned model. It is mathematically illustrated as follows:

$$\Delta y_{it} = \alpha_0 + \sum_{j=1}^{p} \beta_j\, \Delta y_{i,t-j} + \sum_{k=0}^{q} \Upsilon k\, \Delta x_{i,t-k} + \delta_1 y_{i,t-1} + \varepsilon_{it} \quad (3)$$

where Δy_{it} is the first difference of dependent variable for i^{th} (unit of cross-section) and t^{th} (time); $\Delta x_{i,t}$ represents the first difference of independent variables for i^{th} (cross-section unit) and t^{th} (time); p and q are the lag orders for the dependent and independent variables; $y_{i,t-1}$ are the lagged period of the dependent variable; α_0 is the constant; β_j and Υk are short-run lagged differences on dependent and independent variables; δ_1 represents the long-run.

3.2.2. Dynamic Fixed Effects Auto-Regressive Distributive Lags (DFE-ARDL)

This model is most often looked upon as an extension of the ARDL model. This model's peculiarity is that it considers aspects relating to fixed and dynamic attributes of the data type, usually panel. The DFE-ARDL method is used when there is a potential relationship among the variables and when controlling character-specific aspects of the data. The model is illustrated below as follows:

$$\Delta y_{it} = \alpha_1 + \sum_{j=1}^{p} \beta_j \, \Delta y_{i,t-j} + \sum_{k=0}^{q} \Upsilon k \, \Delta x_{i,t-k} + \delta_1 y_{i,t-1} + \varepsilon_{it} \tag{4}$$

where Δy_{it} is the first difference of dependent variable for i^{th} (unit of cross-section) and t^{th} (time); $\Delta x_{i,t}$ represents the first difference of independent variables for i^{th} (cross-section unit) and t^{th} (time); p and q are the lag orders for the dependent and independent variables; $y_{i,t-1}$ are the lagged period of the dependent variable; α_i represents each cross-section's fixed effects; β_j and Υk are short-run lagged differences on dependent and independent variables; δ_1 represents the long-run. The methodological workflow of this research is presented in Figure 2.

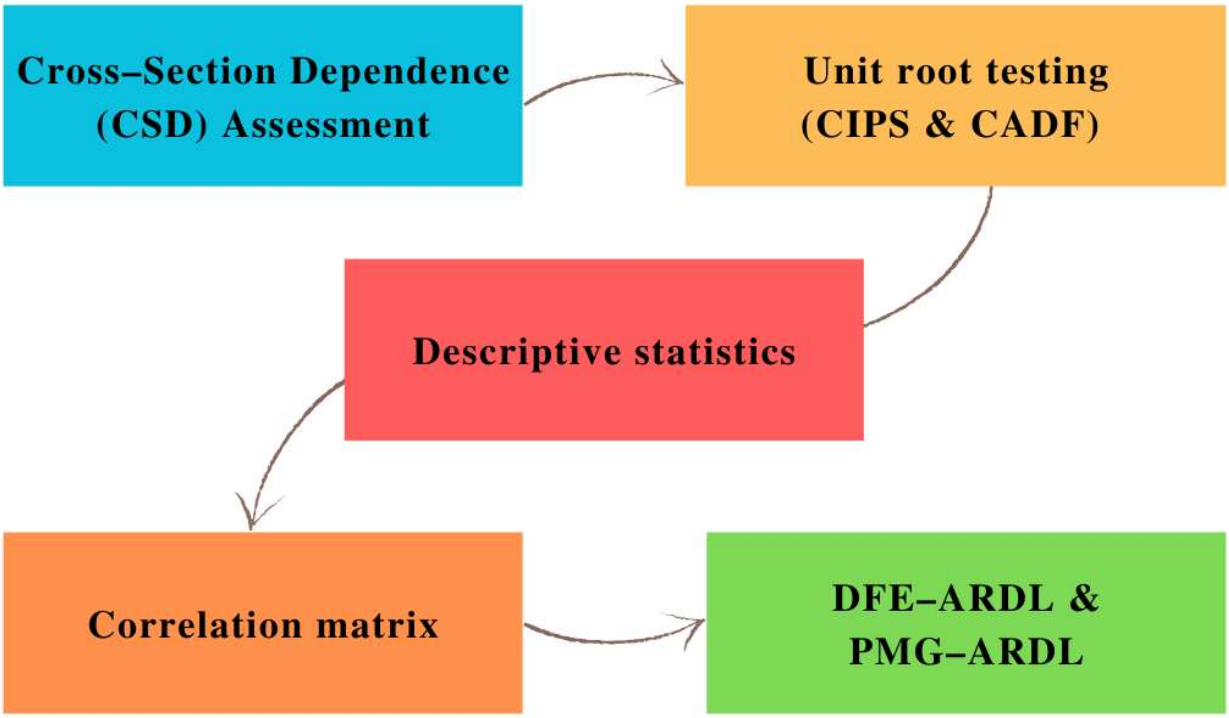

Figure 2. Methodological workflow.

4. Empirical Findings and Discussions

4.1. Cross-Section Dependence (CSD) Assessment

Before verifying the occurrence of unit roots within the series, it is important to ascertain the possible existence of CSD within the model's variables. Table 2 displays CSD within the panel series relative to their probability values. Table 2 confirms the presence of CSD among the variables because the *p*-values are less than 5%. This means the second-generation unit root test will be appropriate for this study.

Table 2. Cross-Sectional Dependency test results.

Test	Statistic	Probability
Breusch-Pagan LM	50.07444	0.000 *
Pesaran Scaled LM	8.960916	0.000 *
Pesaran CD	5.171321	0.000 *

Note: * implies $p < 0.01$.

4.2. Unit Root Testing

Table 3 illustrates the Pesaran-CIPS and CADF unit root tests, which are second-generation tests. The outcome of the CIPS test shows that REC, POP, and GLO are not stationary (I(0)), while CO_2, GDP, and FD are stationary. In addition, all variables are stationary at (I(1)). For the CADF test, all variables are stationary at (I(1)). The combination of both tests shows a mixed order of integration.

Table 3. Pesaran-CIPS and CADF panel unit root test results.

Variables	CIPS		CADF	
	I(0)	I(1)	I(0)	I(1)
CO_2	–3.230 **	–5.715 **	–2.246	–2.854 ***
REC	–1.013	–5.051 ***	–0.231	–1.462
GDP	–3.377 ***	–4.445 **	–2.763	–3.043 **
POP	–1.380	–5.195 *	–0.904	–2.958 ***
GLO	–2.007	–4.838 **	–2.097	–2.660
FD	–3.037 **	–5.813 ***	–2.598	–3.510 *

Note: * implies $p < 0.01$, ** implies $p < 0.05$; *** implies $p < 0.1$.

4.3. Descriptive Statistics

Table 4 illustrates the descriptive statistics. The highest mean (82.19) and median (82.35) are observed in variable GLO, while the lowest mean (0.48) and median (0.46) are observed in POP. There is a minimal occurrence of outliers in the aforementioned variables buttressed by the closeness seen from the resultant differences between the mean and median values and from the maximum and minimum values. In addition, CO_2, REC, GDP, and GLO are platykurtic, given that their kurtosis coefficients are less than 3, while POP and FD are leptokurtic, given that their coefficients are greater than 3. Moreover, all the variables in the model do not follow a normal distribution, as reinforced by their probability values. The sufficiency of the panel data is justified by the availability of 155 observations. Table 5 also shows the correlation matrix, and it establishes that REC, POP, and FD positively correlate with CO_2, while GDP and GLO are negatively correlated with CO_2.

Table 4. Descriptive statistics.

	CO_2	REC	GDP	POP	GLO	FD
Mean	9.23	10.89	28.33	0.48	82.19	0.72
Median	8.53	10.54	28.31	0.46	82.35	0.75
Minimum	3.95	0.61	27.47	−1.85	67.55	0.35
Maximum	17.38	23.85	28.91	1.50	89.45	0.95
Std. Dev	3.75	7.22	0.33	0.45	4.94	0.13
Skewness	0.82	0.25	−0.54	−0.93	−0.57	−0.82
Kurtosis	2.47	1.80	2.93	6.83	2.80	3.32
Jarque Bera	19.22	10.83	7.77	116.70	8.64	18.36
Probability	0.00	0.00	0.00	0.00	0.01	0.00
Observation	155	155	155	155	155	155

Table 5. Correlation matrix.

Variables	CO_2	REC	GDP	POP	GLO	FD
CO_2	1.0000					
REC	0.4839	1.0000				
GDP	–0.5650	–0.5144	1.0000			
POP	0.5188	0.4128	–0.4435	1.0000		
GLO	–0.2444	0.0362	0.6707	–0.0545	1.0000	
FD	0.1155	0.1537	0.2928	0.1946	0.7818	1.000

4.4. Regression Results

4.4.1. Dynamic Fixed Effect Results

The results retrieved from the DFE-ARDL analysis are illustrated in Table 6. The LR and SR analysis of the model are presented. Based on the LR analysis, REC, GDP, and POP are statistically significant at 5%, 5%, and 10%, given that the probability values are lower than 0.05, 0.05, and 0.1, respectively. Hence, we can reject the null hypothesis that REC, GDP, and POP do not significantly affect CO_2. Thus, an average increase in one unit of REC, GDP, and POP will decrease CO_2 by about 0.218%, 5.276%, and 1.215%, respectively. The other variables, GLO and FD, are statistically insignificant. Thus, they exert no influence on CO_2. Regarding the SR scenario, REC, GDP, POP, and FD are statistically significant at 5%, 1%, 1%, and 5%, given that their probability values are below 0.05, 0.01, 0.01, and 0.05, respectively. Hence, REC, GDP, POP, and FD affect CO_2. Thus, an average increase in one unit of REC, FD, GDP, and POP will lead to an estimated decrease in CO_2 of about 0.087% and 1.468% and a corresponding increase of about

6.153% and 0.220%, respectively. GLO is not statistically significant and hence exerts no influence on CO_2. The ECT (–0.136) is negative and statistically significant, demonstrating a LR relationship between our variables of interest. This illustrates the speed at which the model adjusts to the long-run equilibrium situation relative to the occurrence of shocks.

Table 6. DFE-ARDL results.

Long-Run (LR) Estimation	Coeff.	Z	p > /z/
REC	–0.218	–2.41	0.016 **
GDP	–5.276	–2.15	0.031 **
POP	–1.215	–1.73	0.084 ***
GLO	0.112	0.62	0.539
FD	1.001	0.26	0.798
Short-run (SR) Estimation			
ECT	–0.136	–3.56	0.000 *
REC	–0.087	–2.12	0.034 **
GDP	6.153	5.89	0.000 *
POP	0.220	2.68	0.007 *
GLO	0.007	0.23	0.818
FD	–1.468	–2.11	0.035 **
C	20.577	2.39	0.017 **

Note: * implies $p < 0.01$, ** implies $p < 0.05$, *** implies $p < 0.1$.

4.4.2. PMG-ARDL

The results retrieved from the PMG-ARDL analysis are illustrated in Table 7. The LR and SR analysis of the model are presented. Based on the LR analysis, an average increase in one unit of REC and GLO will decrease CO_2 by 0.225% and 0.123%, respectively. The other variables, GDP, POP, and FD, are statistically insignificant and thus do not affect CO_2. Regarding the SR, an average increase in one unit of GDP and FD will lead to an increase in CO_2 of about 5.854% and a corresponding decrease of about 0.666%, respectively. REC, POP, and GLO are not statistically significant; hence, they do not affect CO_2. The ECT is statistically significant and negative, showing that the economy will return to equilibrium at an adjustment speed of 0.24%.

Table 7. PMG-ARDL results.

Long-Run (LR) Analysis	Coeff.	Z	p > /z/
REC	–0.225	–4.74	0.000 *
GDP	2.143	1.07	0.285
POP	–0.388	–1.03	0.304
GLO	–0.123	–2.70	0.007 *
FD	–1.095	–0.65	0.518
Short-run (SR) Analysis			
ECT	–0.245	–2.00	0.045 **
REC	–0.124	–1.34	0.181
GDP	5.854	2.38	0.018 **
POP	0.037	0.24	0.809
GLO	0.014	0.81	0.418
FD	–0.666	–1.85	0.065 ***
C	–9.892	–1.90	0.057 ***

Note: * implies $p < 0.01$, ** implies $p < 0.05$, *** implies $p < 0.1$.

4.5. Discussion

Based on DFE-ARDL analysis, both the SR and LR estimates illustrate a negative relationship between REC and CO_2. This suggests that the countries are intensely involved in the use of renewable energy as well as effective environmental sustainability measures. This also confirms the environmentally friendly nature of clean energy sources. The PMG-ARDL approach also showed that REC had a non-significant negative impact on CO_2, while the LR results are similar to the DFE-ARDL findings. The inherent demonstrated inverse relationship between REC and CO_2 is backed by existing literature [17,18,21,22,53].

Secondly, the SR estimates of DFE-ARDL analysis confirmed a positive association between GDP and CO_2. This implies that as the country grows, so does CO_2 increase, given that the policies and frameworks geared towards the reduction of CO_2 are still under either assessment or are yet to be fully implemented. However, a negative connection between GDP and CO_2 is established in the LR. This implies that the earlier set policies and frameworks geared towards environmental sustainability have become effective. Hence, the growth of the country in no way harms the environment. The PMG-ARDL results are also similar, except for the LR result, which is positive and insignificant. The positive link between GDP and CO_2 is supported by [29] for Pakistan, ref. [30] for SSA economies, and [31] for BRICS. On the contrary, the inverse association between GDP and CO_2 is confirmed by [27,32].

Furthermore, the DFE-ARDL results established that POP increases CO_2 in the SR and reduces CO_2 in the LR. This means that as the economy grows, so does the population develop in terms of their level of education. This educational attainment makes people more concerned about preserving their environment, thus avoiding energy sources and policies that deplete their environment. In addition, this new knowledge enables the population to adopt birth control measures and embrace and implement demographic related measures such as family planning, demographic transitioning and urbanization, which significantly decrease CO_2. This viewpoint is corroborated by [34] for East Asian economies and [35] for China. On the contrary, the positive link between POP and CO_2 is justified by the absence of birth control measures and other measures associated with population demographics, which, in turn, accelerates CO_2. This corresponds with the studies of [42] for the global economy and [36] for China. The following studies also found no link between POP and CO_2 [33,38].

Based on the DFE-ARDL findings, this research also established that GLO reduces CO_2 in the LR. The implication is that the countries considered in this study are implementing GLO-related policies such as green finance, innovation and technology transfer, and involvement in global environmental agreements, which benefit the environment. This outcome is supported by [39,41–43,52].

Finally, estimations based on DFE-ARDL illustrate an inverse relation between FD and CO_2 in the SR. However, FD exerts no influence on CO2 in the LR, given that it is statistically insignificant. The estimations based on PMG-ARDL also illustrate a negative relationship in the SR, which is justified by the implementation of some policies such as carbon pricing and green investment. The negative FD-CO_2 nexus is confirmed by [52] for APEC economies and [53] for top renewable energy economies. The study outcome is further presented in Figure 3.

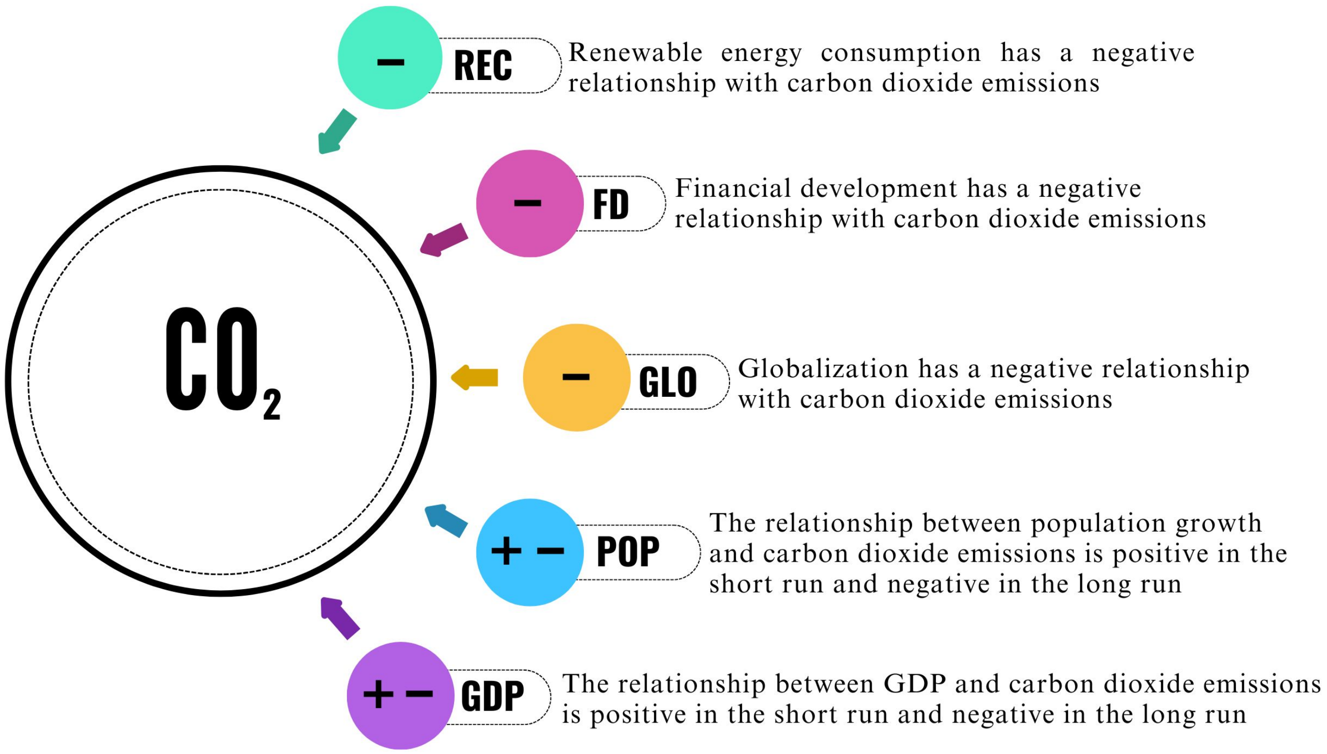

Figure 3. Study outcome.

5. Conclusions and Policy Recommendations

This study ascertains the extent to which renewable energy consumption (REC), economic growth (GDP), population growth (POP), globalization (GLO), and financial development (FD) affect carbon dioxide emissions (CO_2) in selected G7 economies (France, Germany, Canada, Italy, and the United Kingdom) from 1990–2020. DFE-ARDL and PMG-ARDL methods were employed for analysis. The empirical findings for DFE-ARDL showed that REC, GDP, and POP have an adverse association with CO_2 in the long-term. However, in the short-term, REC and FD improve the environment, while GDP and POP drive CO_2. It is observed that the result for REC in the short and long-run is consistent. The PMG-ARDL results revealed that REC and GLO negatively affect CO_2 in the long-run, and in the short-run, GDP spurs CO_2, while FD reduces it.

The policy recommendation concerning this study is aggregately based on the results retrieved from DFE-ARDL and PMG-ARDL. Thus, the investigated countries should focus on the investment and utilization of renewable energy, given that both the SR and LR impact is negative. More funding should be allocated to research and development of new and better renewable energy sources, which will further mitigate CO_2. Aside from the above, to further mitigate CO_2, the countries can adopt and implement globalization endeavors such as innovation and technology transfer, global campaign awareness, and green investment financing, which will go a long way toward delimiting CO_2.

Furthermore, the reconstruction and revitalization of areas involved in the extraction and exploitation of renewable energy sources should be implemented, as this would help replenish and sustain the environment, thereby reducing CO_2 emissions. Additionally, using clean energy technologies stemming from renewable energy sources should be encouraged, improved and implemented, as this goes a long way to mitigate the CO_2. Besides, decision-makers and stakeholders are encouraged to carry out investment activities characterized by less human intervention to maintain the ecology and the environment.

It is also essential to mention the strategies by which GDP can be decoupled from CO_2. These strategies include transitioning to renewable energy, as previously recommended, adopting energy-enhancing technologies, promoting sustainable production and consumption, implementing carbon pricing and incentives, and strengthening environmental regulations. Despite this study's outlined relevance and importance, it is equally plagued with limitations. First, there are two G7 economies for which data is not accessible. Consequently, five nations were chosen from the G7 economies, preventing the most comprehensive results. Second, the case study only focuses on the G7 economies, meaning its findings cannot be generalized. Thus, other country classifications such as BRICS, MENA, OECD, and E-7 can be examined in prospective publications to verify the generality of the derived results from this research. Third, the study does not account for issues related to nonlinearity, possibly existing amongst the variables. As a result, nonlinear econometric techniques can be employed in further studies. Fourth, the study period slatted from 1990 to 2020 reduces the comprehensiveness of the results, which in the long-term mitigates the intended completeness of the study's empirical outcome. Further studies can employ a large data set with extended years.

For further studies, a host of environmental sustainability variables, inclusive of green investment, green finance and green trade should be included in future research for more clarity, traceability and increased reliability. In addition, advanced econometric techniques can be employed.

Author Contributions

Conceptualization, A.A.E. and O.A.S.; Methodology, A.A.E. and O.A.S.; Software, A.A.E. and O.A.S.; Validation, A.A.E., O.A.S and H.O.; Formal Analysis, A.A.E.; Investigation, A.A.E.; Resources, A.A.E. and O.A.S.; Data Curation, A.A.E.; Writing—Original Draft Preparation, A.A.E. and O.A.S.; Writing—Review & Editing, A.A.E. and O.A.S.; Visualization, O.A.S.; Supervision, H.E.; Project Administration, O.A.S. and H.O.; Funding Acquisition, None.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The authors confirm that all data generated or analyzed during this study are included in the data section of our article. In addition, data will be available upon request.

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