International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

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The effect of global collaboration on climate mitigation technologies in reducing CO_2

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International Journal of Science and Research Archive, 2024, 13(01), 2071–2086

Publication history: Received on 23 July 2024; revised on 04 September 2024; accepted on 06 September 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.13.1.1891

Abstract

The fundamental approaches to industrial growth, government interventions, and market structure have ignored the main consequences of the common idea of "growth first, clean later". This study investigates the relationship between carbon emissions (CO_2) and international collaboration in climate change mitigation technologies (ICCCMT), renewable energy consumption (REC), exports (EXP), imports (IMP), gross domestic product (GDP), foreign direct investment (FDI), natural resources rents (NRR), and domestic innovation in climate change mitigation technologies (DICCMT) for a panel of the Organization for Economic Cooperation and Development (OECD) countries over the period of 1990-2020. We adopted a series of econometric techniques for the visualization of the available data. We used second-generation econometrics estimations to verify cross-sectional dependence, co-integration, and stationary between the variables.Based on our findings, the study reveals that ICCCMT, REC, and DICCMT have a positive effect and contribute to CO_2 mitigation of the 30 OECD economies. Furthermore, the findings reveal that ICCCMT can promote renewable energy consumption, thus the increase of REC will significantly mitigate CO_2 emissions. The outcomes from the panel dynamic GMM model confirmed a positive relationship between CO_2 emissions, FDI, exports, imports, and GDP. The study indicates that these variables can adversely affect climate change mitigation.

Keywords: Global collaboration; Climate change mitigation technologies; Environmental sustainability; CO_2

1. Introduction

Climate change mitigation has become a crucial subject globally and its impacts at the national level are dynamic. Numerous research study declared that climate change mitigation has become at the center of debates and concerns around the globe. Hence, the importance of International Collaboration has become a dominant idea, considering the different levels of CO2 emissions with an unequal degree of impact among countries. Less developing countries marked massive needs for energy access, while developed countries contribute a third of carbon dioxide CO2 emissions, such as China, Germany, and the USA. According to [1], there are 16.75 billion metric tons of carbon dioxides emissions which about 29.18% is accounted for in China, followed by the US with 14.02% in 2020. Improving energy efficiency and reducing fossil fuels are the leading options for global climate change [2]. Undoubtedly, the need for shifting to cleaner energy became a significant challenge of the 21st century considering the increase of extreme events that occurred, such as floods sweeping through different parts of China and Germany, and fires sparked by record temperatures across countries, namely Turkey, Greece, and Italy.

Regardless of the increasing economic growth, climate change mitigation is inevitable, and countries are required to anticipate any unexpected outcomes. Thus, the relationship between CO2 emissions and economic growth is highly debated, where the discussion differs on whether it is a positive relationship. It was acknowledged by the Kuznets Curve hypothesis in showing the U-shaped relationship between pollution level and the income, which came out with the suggestion that any extra use of fossil fuels increases the level of pollution [3,4]. Moreover, the existing factors that affect

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climate change are the core interests of researchers who endorsed climate change mitigation. The driving forces are separately presented in the matter of their baneful and beneficial impacts. Nevertheless, the pivotal connection between the factors themselves forms a sequence of unfinalized functions. Our research covers the dominant features such as fossil fuel, renewable energy consumption, industrial activities, exports, imports, foreign direct investment, and technology and innovation.

To surrender the conventional methods, renewable energies have a clear mandate in providing clean, abundant energy gathered from the sun, wind, earth, and plants. The share of global renewable sources increased to 3% surpassing other fuel sources in 2020, and the energy demand decreased during the COVID19 crisis due to the prolonging restrictions on movement [4]. According to [5], green technology innovation has played a pivotal role in preventing GHG and achieving carbon neutrality goals. However, the sustainable solutions considering climate change mitigation adopted by many countries calls for the acquisition of technology and innovation. For instance, the United Nations (UN) announced 17 sustainable development goals of which energy is an ultimate target regarding technological innovations [6]. Undoubtedly, negative externalities cannot be addressed on an individual basis, it rather requires a global mechanism to understand to what extent collaboration in technology has a positive impact on climate change mitigations.

In this research, we design the following questions:

- Does the current speed in technological innovation sufficient to achieve the goal of 2030 for climate change mitigation?
- To what extent international collaboration in climate change mitigation technologies is crucial?
- are OECD countries doing enough to tackle climate change mitigation under the current measures?

The study will contribute to the discourse on how ICCCMT can tackle CO2 emissions. The gaps surrounding the goals overall are related to the uncertainty and the complexity of measures. Thus, achieving net-zero GHG emissions under the Paris agreement will be easy when achieving net-zero CO2 emissions. CO2 s require rapid decolonization and overcoming hurdles for non-CO2 emissions [7]. For global climate actions, technology is described to be the key element therefore the deployment of low-carbon technologies confronts technological difficulties or limited political support. Therefore, delayed actions lead to higher costs, increase the distributional impacts between countries, and lock economies into carbon-intensive infrastructure. In particular, the improvement of energy efficiency through less carbon-intensive coal, using nuclear energy, renewable energy sources, the integration of electric grid, and electric transport system are the habitual promising methods to alleviate fossil fuel dependency.

2. Literature Review

2.1. Overview of the international collaboration in climate change mitigation technologies

Politically, the Paris agreement contains a set of successful climate change mitigation schemes that provide a global outline of the environmental agreements. [8] hypothetically examined the political achievements of the policy diplomacy since the launch of the Paris- agreement. The study mentioned that climate diplomacy has been achieved successfully due to the relevant international conversation and convincing arguments about the economic benefits of climate actions. Additionally, the success of the Paris Agreement depends on the effectiveness of the global climate governance mechanisms [9,10] revealed that addressing climate change with technology mandates, standards, or incentives (i.e., knowledge sharing, R&D, and technology transfer) could be cost-effective when well-targeted and designed.

Adam B Jaffe [11] cited that building on climate change technologies is a long-term process that requires a long-term view. Rather, the failure of some policies has to be used to improve particular programs, not to justify the failure itself. [12] addressed that the full solution of climate change concerns includes the adaptation of new technologies and the engagement of the developing countries to the global transition. Reflecting the gravity of climate change, climate change mitigation technologies play a crucial role in collaborative efforts [13]. Climate change mitigation technologies can decrease GHG emissions and promote efficiency level. Moreover, [14]) stressed that climate change mitigation technologies are significantly related to Eco-efficiency. Comparatively, technological projects for climate change reduction require significant innovation and development, knowing that environmental concerns should be one of the top priorities at present [15,16,17]

2.2. Peremptory challenges from carbon dioxide emissions around the globe

Theoretical and empirical perspectives observed the correlation between climate change and the number of influencing factors, such as energy consumption, economic drivers, renewable energy, technology, and urbanization [19,20]. The debate is broadening out to cover further factors, including ICTs, political stability, and governance [21, 22]. Mitigating CO2 emissions is the world's enormous concern of the 21st century, and thus international collaboration is essential for the validation and authentication of policy outputs under international agreements. Efficient mitigation actions do not require international collaborations uniquely but also cooperation among different sectors and actors. Therefore, the complimentary of national and international regulations is required for assessing the effectiveness of policies [23,24]

The prominent approach among environmental issues studies is the standard econometrics for causality analysis between the dependent and independent variables. Where researches focused largely on the relation between GDP and energy consumption, or the income level and carbon emissions. In particular, energy consumption is recognized as the major factor of GHG emissions in China [25], Japan [26,27], India [28], USA [9,30], and Pakistan [31]. [32] analyzed the factors behind the growth of CO2 emissions by using an index decomposition technique for more than 100 countries, the results revealed that economic growth and population growth are the main drivers of the emissions over 35 years. Nevertheless, the empirical observation from the testing of environmental Kuznets curve (EKC) hypothesis is related to the investigation of the relationship between output and pollution level. [33] classified this relationship into three types, including scale, composition, and technique effects; The scale effect refers to the association between the size of an economy and the provision of environmental services. Whereas, the composition effect concerns the change in reallocation of productive resources among sectors. The final type considers that production processes and consumption may alter the ratio of pollution when considering new technology and environmental policies to reduce pollution level.

Technical progress is considered to be an important way to effectively reduce carbon emissions. Undoubtedly, each country has a different economic structure, level of development, and energy consumption. The nexus on the relationship between CO2 emissions, energy consumption, and economic growth studied in a group of countries from different organizations answers the prevailing distinctions characterized in economic, social, environmental aspects, and political ones. According to [33], there are groups of economies that participated in the European Economic Union (EU) form an economic, social, and political coalition albeit having independent economic and development structures. Thence, the energy growth nexus is fairly similar and homogeneous among these countries which ought to be accommodated globally. The importance of sustainable development has been recognized by the OECD council earlier as a key priority for the consolidation. The first demarche is illustrated in strengthening the elaboration of the organization's strategy for wide-ranging efforts in technological development, sustainability indicators, and the environmental impact of subsidies [34]. Additionally, through engaging OECD members for valuable dialogues on shared analysis and development strategies for implementing sustainable development [35].

2.3. Renewable energy and CO2 emissions nexus

In consonance with the limitation of CO2 emissions, various alternative renewable energy sources (i.e., solar energy, hydroelectric energy, wind energy) substitute the conventional production of energy from non-renewable sources. Countries attempting to promote their economy through clean energies in respect of environmental regulations seem to be in line with the global energy perspective, however, countries relying on non-renewable sources are lagged behind the standards, although they have leveraged their extractive resources to promote their infrastructures and restrain their poverty [35]. Consequently, low emissions energy sources promote emerging economic opportunities, facilitate energy technology and innovations, together with the development of energy distribution [36,37].

The implementation of clean energies has been qualitatively assessed in some recent studies and approved that renewable energy has a negative impact on CO2 emissions in China, in contrast with a bidirectional causality running from CO2 emissions to renewable energy [38,39]. On the other hand, many researchers analyzed non-renewable energy nexus with CO2 emissions and proved bidirectional causalities running from CO2 emissions and non-renewable energies to renewable energies. Thus, the noticeable circumstances of the two driving forces lead to a diverging direction in terms of their impact on the climate, seeing that both require a set of measures to address the global requirements regarding renewable energy initiation and reduce the demand for conventional energy sources.

Renewable energies and CO2 emissions relationship have been clearly disclosed for materializing the actual environmental conditions. According to numerous studies, renewable energies are undeniably assisting the decrease of CO2 emissions.[40] investigated the situation of renewable energies installation in China from 2010 to 2020 by employing the C-GEM model. The study revealed that more renewable energy installation has created more favorable conditions for renewable energy electricity and it has contributed to a decrease of CO2 emissions intensity by 2%. A study on Thailand analyzed the impact of renewable energy on CO2 emissions from 1980 to 2018 [41]. The empirical outcomes from the ARDL stimulation model stressed that renewable energy has a negative impact on CO2 emissions in the short run. Additionally, [42] examined the impact of renewable energy on energy security risk for 23 OECD countries. According to the result from the Augmented Mean Group the total number of renewable energies reduces energy security risk. However, the results may not be valid for all countries in the organization due to the lack of policies implementation for energy security risk.

2.4. Technology, innovation and CO2 emissions nexus

The unremitting linkage between the driving factors is expanding our research study. Relatively, early phases of industrialization marked a high level of pollution, regarding the insufficient adoption of energy technologies with uncertainty related to environmental degradation [43]. The aforementioned effects in natural resources rents assert that only cleaner technologies adaptation will lead to an increase in environmental quality [44]). By employing the environmental Kuznets curve hypothesis for 28 OECD countries, the study found that energy technologies seem to be efficient for climate change mitigation. A recent study by [45] suggested green technologies for CO2 mitigation s via FDI in order to improve the environmental quality.[46] stressed the importance of technology diffusion through domestic and international trade for economic growth.

Bin Xu [47] investigated the role of the high-tech industry on climate change mitigation in 30 Chinese provinces. The finding of the study showed that the high-tech industry is significant for emissions reduction by using the STIRPAT model from 1999 to 2015. Similarly, [48] addressed the evilness of technology spillover in reducing CO2 emissions from 1997 to 2018. Although the study did not scrutinize only technology spillover, also it added the impact of intellectual property rights (IPR) and transportation infrastructure (TI). The findings revealed that IPR and TI levels have a crucial role in technology spillover, thus they should be well adapted in a matter to maximize environmental quality. The result of [49] revealed that innovation is a momentous part of any given solution for climate change mitigations. The study employed the innovation-EKC model for 28 OECD countries from 1990 to [50] carried out the diffusion of patented inventions in thirteen climate-mitigation technologies classes. The finding of the study disclosed that innovation in climate change technologies is distinctly concentrated in Japan, Germany, and the USA. Moreover, the study proposed cooperation in developed inventions for developing countries.

3. Exports and imports and CO2 emissions nexus

The lengthy debate on the impact of international trade on climate change has been reviewed by numerous studies. [51] examined the impact of exports and imports on two measures of CO2 emissions for Saudi Arabia, Russia Qatar, and other 5 oil-exporting countries. the result revealed that exports and imports are significant on the consumption-based CO2 and insignificant on the territory-based CO2 emissions. [52] probed the existence of territory-based CO2 and consumption-based CO2 in a panel of 20 Asian countries. the findings endorsed that trade has an insignificant impact on territory-based CO2 emissions, contrasted to the consumption-based CO2 emissions.

Najaf Iqbal [53] investigated the role of export diversification for 37 OECD counties from 1970 to 2019. The finding indicated that export diversification followed by economic growth affect positively carbon dioxide emissions by using the augmented mean group. The trade variables related to the changes in CO2 emissions are investigated by [54]. The study found that trade volume including domestic products and exports can drive the change of the emissions by employing the production- based index decomposition analysis (P-IDA) and consumption-based (C-IDA) to investigate the demands of economies including domestic and imports products, the findings stressed that exports with a growing share of GDP stimulated the total emissions, while the exports composition became marginally greener. [55] focused on the consumption-based carbon emissions for the Regional Comprehensive Economic Cooperation (RCEP) economies during the period of 1990 to 2020. The empirical outcomes of the study showed that imports extended in (CCO2) and exports manifested in mitigating effect along with renewable energy supply.

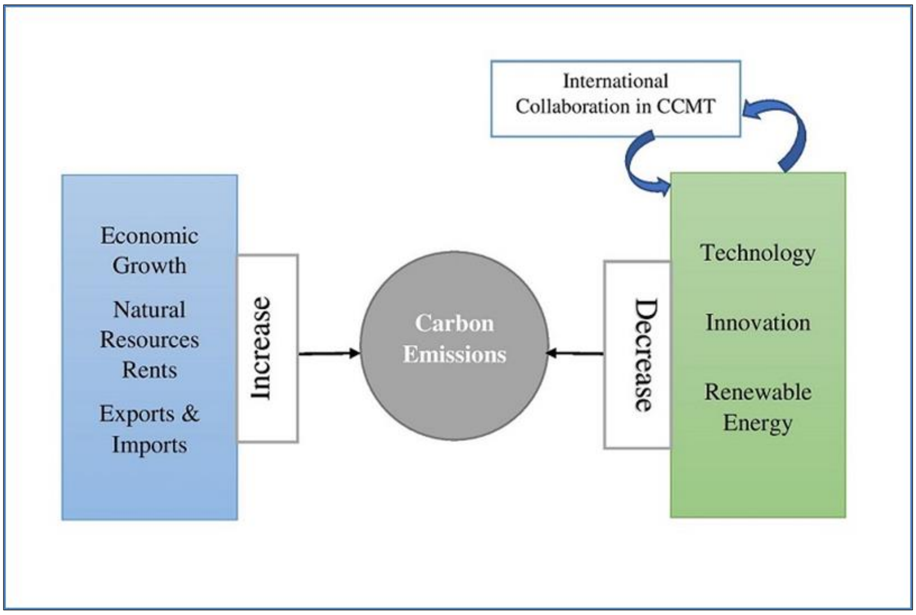

Figure 3 Conceptual Framework

4. Econometric Strategy

4.1. Data source and variables explanation

This study explores the relationship between carbon dioxide emissions (CO2) and various factors, including international collaboration in climate change mitigation technologies (ICCCMT), domestic innovation in climate change mitigation technologies (ICCMT), renewable energy consumption (REC), and natural resources rent (NRR). CO2 emissions are assessed on a per capita basis, while ICCCMT represents the total output of technological innovations aimed at addressing climate change. Domestic innovation is expressed as a percentage of innovation within each country, and gross domestic product (GDP) is reported in per capita US dollars. The analysis also considers exports and imports measured as total goods and services in US dollars, along with foreign direct investment (FDI) inflows. Data for the study were sourced from the OECD database, covering annual time series from 1990 to 2020.

Table 1 The illustration of variables

Variable	Definition	Source	Period
CO_2	CO_2 emissions in per capita	OECD	1990-2020
ICCCMT	International collaboration in climate change mitigation technologies Total output	OECD	1990-2020
DICCMT	Domestic innovation in climate change mitigation technologies in (%) per country	OECD	1990-2020
REC	Renewable energy consumption is the total output of renewable sources-solar, wind, and hydroelectric the (%) of the totals	OECD	1990-2020
GDP	gross domestic product per capita in ($US)	OECD	1990-2020
FDI	Foreign direct investment net inflows $US	OECD	1990-2020
NRR	Natural resources rents, total natural resources in (%)	OECD	1990-2020
EXP	Export is the volume of the total of goods and services in ($US)	OECD	1990-2020
IMP	Imports is the volume of the total of goods and services in ($US)	OECD	1990-2020

4.2. Proposed models

CO2 =ICCMT, DICCMT, REC, GDP, FDI, NRR, EXP, IMP …………Eq. (1)

The suggested model is presented in Eq. (1). CO2 emissions are the dependent variable indicated as CO2 emissions per capita. International collaboration in climate change mitigation technologies (ICCCMT) is denoted as the total output of climate change mitigation technologies. Domestic Innovation in climate change mitigation technologies (DICCMT) described as the percentage of domestic innovation in patents, R&D, policies design, and investments. Renewable energy consumption (REC) described as the total output of renewable sources such as solar, wind, and hydroelectric. Gross domestic product (GDP) is in $US. Foreign direct investment (FDI) denoted as net inflows in $US. Natural Resources rents are countries' percentage in total natural resources. Trade openness is export and import trade in $US.

$CO2_{it}$= β (0_{it}) +β(1) ($ICCCMT_{it}$)+β_(2) $(DICCMT)_{it}$ +β_3 $(REC)_{it}$+β_4 $(FDI)_{it}$+$(β\_5\ NRR)_{it}$+β_(6) $(EXP)_{it}$+β_7 $(IMP)_{it}$+ β_k ∑_(1=0)^2▒〖control_(i,t) 〗 +it country effects +αyear effects…………

Eq. (2)

In Eq. (2), 'i" is the total observation of a cross-section of selected economies. "t" is the total number of years (1990-2020). CO2 emissions is a natural logarithm from CO2 emissions per of carbon dioxide; (ICCCMT) is international collaboration in climate change mitigation technologies; (DICCMT) is the domestic innovation in climate change mitigation technologies;

(REC) represents renewable energy consumption; (FDI) is the foreign direct investment ($US), (NRR) indicates the natural resources rents (%); (EXP) is exports of goods and services ($US), Imp is imports of goods and services; GDP is estimated as the real GDP per capita.

4.3. Correlation statistics

4.3.1. The multicollinearity tests

It is needed for specific characteristics of data and not for the statistical aspects of the linear regression model. Specifically, when two or more independent variable are correlated the standard error of the coefficient will increase, which make the coefficient become very sensitive to small changes in the model [56].

4.3.2. The serial correlation tests

It is held a central role in the statistical analysis, the serial correlation measures the relationship between a variable's current value given its past value [57,58].

4.3.3. Variance inflation factors (VIF)

It helps to identify the degree of multicollinearity and the effect of multiple variables on a particular outcome or the dependent variable. In a word, the VIF is a measurement where we can detect which variable in the data is highly correlated with other variables [59]

4.3.4. Heteroscedasticity test

It tests whether the variance of the errors form a regression is dependent on the values of the independent variable. The second step represents correlation methods which allows to measure the relationship between selected factors, and the multiple regression methods to assess the effect of each indicator on the final one, including; the Panel Unit Root Test, Cross Sectional Dependence Test, Panel Co-integration Test, Granger causality tests and dynamic fixed effects, pooled mean group and mean group estimation.

4.4. Panel unit root tests

It addresses the null hypothesis and designed for null hypothesis of a unit root for each individual series in a panel. Using panel unit root is significantly dynamic compared to the standard time series [60]

CIP ̂S= N^(-1) ∑_(i=0)^nCDF…………..Eq. (3)

4.5. Cross sectional dependence test

We employed cross sectional dependence test by using the Lagrange multiplier (LM) test suggested by [61]and (CD) test developed by [62] to examine the following model:

y_it= a_i β_(it)^' x_it+ε_it ∀_i= 1,2 . . .Nand∀t=1,2 . . .T………..Eq. (4)

The "T" in Eq. (4) denotes the time series magnitude, i signifies the cross-sectional dimension, y_{it} indicates the explanatory variables, x_{it} describes the $I \times k$ vector of observation on the dependent variables, a_i designates the individual intercepts while β_i represents the slope of coefficients collectively. In addition, $I \times k$ and $I \times I$ represent the vectors of parameters to be calculated on the dependent variables that are different across i (cross sectional) and t (time series). Considerably, for every i, ϵ_{it} is considered to be independently identically distributed error terms could be correlated across the cross-section.

In Eq. (1), our null hypothesis H0: we suppose that there is no cross-sectional dependence alongside the alternative hypothesis H1 is as follows:

- H0: (CSD does not exist)
- H1: (CSD exists)

Thus, we used the LM estimation in the context of dynamic seemingly unrelated regression (DSUR) estimation, which it presented in equation 5 as follows,

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N-1} \hat{P}_{ij}^2 \text{ ....Eq. (5)}$$

The P_{ij}^2 from Eq. (5) represents the simple measurement of the pair-wise correlation of the residual in Eq. (1). Moreover, the (LM) test is commonly distributed as x^2 with N (N-1)/2 degrees of freedom under H0, although t is not applicable when N>T, which proposes the subsequent scaled version of the applicable (LM) estimation even as the observation (N) and time (T) are large.

$$CD_1 = \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N-1}\left((T\hat{P}_{ij}^2)-1\right)} \text{ ....Eq. (6)}$$

From the Eq. (6), null hypothesis H:0 with $T \to \infty$ and $N \to \infty$, the cross sectional (CD) test converts to the standard normal distribution.

4.6. Panel co-integration test

To investigate the co-integration among all variables, we used three different statistical approaches: (1) Pedroni integration estimation [63]; (2) Kao co-integration approach [62]; (3) Westerlund [63] which proposes an error correction-based panel co-integration technique.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\alpha'_i}{SE(\alpha'_i)} \text{ ....Eq. (7)}$$

$$G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T\alpha'_i}{\alpha'_i(1)} \text{ ....Eq. (8)}$$

$$P_t = \frac{T\alpha'_i}{SE(\alpha'_i)} \text{ ....Eq. (9)}$$

$$P_\alpha = T\alpha' \text{ ....Eq. (10)}$$

4.7. Panel causality test

In order to evaluate the causal links among the variables we employed [64], a revised form of the non-causality (Granger, 1969). The panel causality test is the effective econometric technique, it offers consistent outcomes nonetheless of T>N or T<N, and (b) it is consistent for both sorts of data heterogeneous or unbalances [65,66]. This estimation assumed from Z-bar and W-bar statistics, such as follows:

$$Z_{i,t} = \alpha_{i,t} + \sum_{j=1}^{P}\gamma_t^j Z_{i,t-j} \sum_{j}^{P}\gamma_t^j T_{i,t-j} \text{ ....Eq. (11)}$$

γ_t^j signifies autoregressive parameters and j is the lag length.

4.8. Fully modified ordinary least square

We employed the Fully Modified Ordinary Least Squares (FMOLS) method to derive consistent estimators for cointegrating relationships based on the specified equation. The FMOLS technique modifies Ordinary Least Squares (OLS) to address implicit endogeneity bias errors, as noted by Khan et al. (2021). This method is particularly effective in situations with mixed normal asymptotic distributions. Using FMOLS, we investigated the dynamic impact of ICCCMT on CO_2 emissions alongside other variables.

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln X_1 + E_t \text{.........Eq. (12)}$$

According the Eq. (12), $\ln CO_{2t}$ is the dependent variable, β_0 signifies the intercept and β_1 represents the vector slope coefficient; $\ln X_1$ is the vector of response variables including ICCCMT. Lastly, E_t is the error term in the equation.

4.9. Dynamic fixed effect

It produces an estimate of the variance of the coefficients across the cross-section units which can be used as a diagnostic tool to judge how widespread a relationship is and whether pooling of the data is appropriate (Diana Weinhold, 1999).

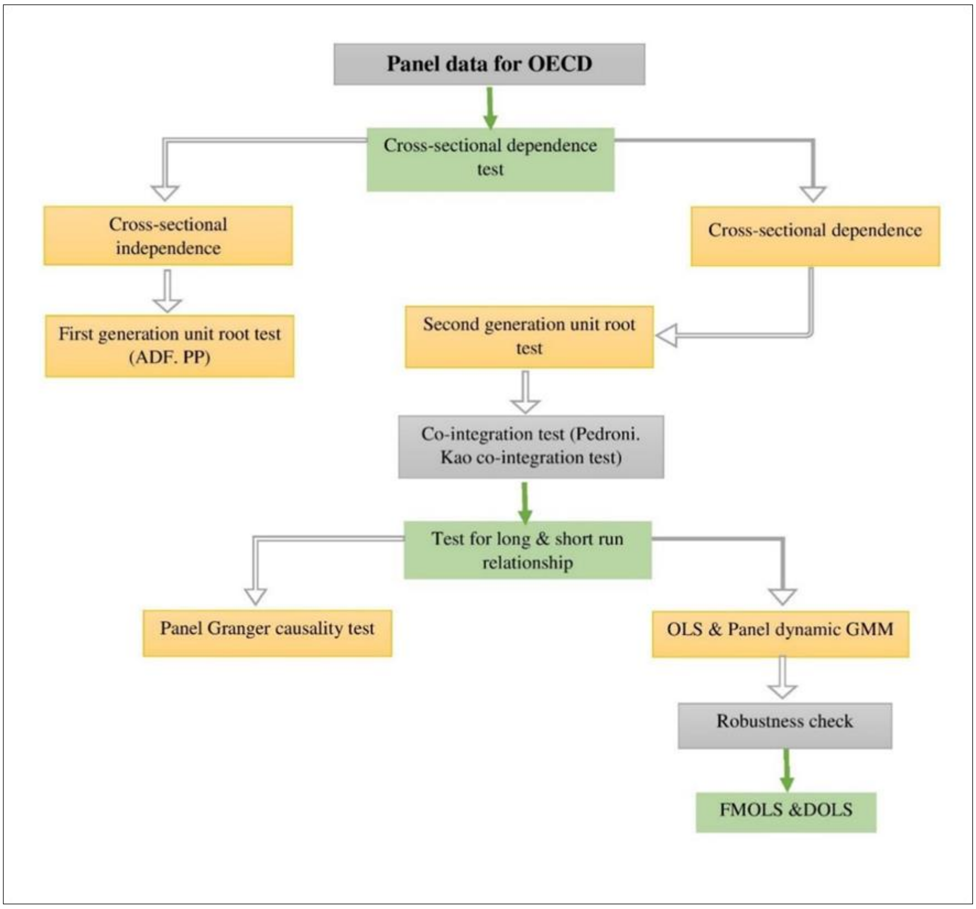

Figure 2 Study modeling plan illustration

5. Results and Discussions

Table 2 Summary statistics

	LICCCMT	LCO$_2$	LDICCMT	LEXP	LFDI	LGDP	LIMP	LNRR	LREC
Mean	1.748	5.093	1.836	11.05	9.929	4.470	11.08	1.102	3.560
Median	1.799	5.000	1.944	11.07	9.949	4.533	11.08	0.337	3.656
Maximum	2	6.787	2.997	12.34	11.86	5.042	12.45	12.307	5.193
Minimum	0.602	3.885	-0.481	9.482	6.301	3.741	10.02	0.087	1.26
Probability	0.000	0.000	0.000	0.026	0.000	0	0.191	0.000	0.000
Observations	680	680	680	680	680	680	680	680	680

Table 2 summarizes the statistics of all selected variables in the thesis, including both response and explanatory variables. The average log value of CO2 emissions across the selected OECD countries is 5.093, with maximum and minimum values of 6.787 and 3.558, respectively. Other key variables include the average log values for LICCCMT (1.748), LDICCMT (1.836), LEXP (11.05), LFDI (9.929), LGDP (4.470), LIMP (11.08), LNNR (1.102), and LREC (3.560), each with their corresponding maximum and minimum values. The total number of observations in the study is 680.

5.1. Correlation matrix

The correlation matrix results presented in the table reveal various relationships among the study's variables. Notably, the relationship between CO2 emissions and ICCCMT is negative, suggesting that ICCCMT can reduce CO2 emissions in the selected OECD countries, a finding supported by existing literature. Additionally, there is a positive and significant correlation between CO2 emissions and natural resources rents, indicating that the exploitation of natural resources tends to increase CO2 emissions. Lastly, a negative relationship between CO2 emissions and renewable energy indicates that adopting renewable and clean energy can help mitigate the adverse effects of CO2 emissions in OECD countries.

Table 3 Correlation matrix

Probability	**LICCCMT**	**LCO₂**	**LDICCMT**	**LEXP**	**LFDI**	**LGDP**	**LIMP**	**LNRR**
LICCCMT								
LCO_2	-12.895	-						
LDICCMT	5.180***	12.58***						
	0.000	0.000						
LEXP	2.925***	20.37***	31.59***					
	0.003	0.000	0.000					
LFDI	-1.551	11.92***	16.70***	27.55***				
	0.121	0.000	0.000	0.000				
LGDP	-10.26	-6.718	15.99***	9.622***	9.099***			
	0.000	0.000	0.000	0.000	0.000			
LIMP	2.875***	25.91***	28.30***	96.53***	27.35***	7.983***		
	0.004	0.000	0.000	0.000	0.000	0.000		
LNRR	1.099	3.244***	1.581	2.785***	2.787***	3.015***	1.539***	
	0.271	0.001	0.114	0.005	0.005	0.002	0.124	
LREC	14.89***	-21.49***	14.32***	16.59***	7.971***	-0.11***	17.42***	8.67***
	0.000	0.000	0.000	0.000	0.000	0.9116	0.000	0.000

*** represent significance at 10%, 5%, and 1% level, respectively

5.2. Panel unit root test

This section presents the main findings from the study's econometric techniques. Table 4 displays the results of the unit-root test, essential for confirming the data characteristics and suitability for econometric analysis. The study employs ADF and PP tests to assess the stationery of the data at the first level or first difference across the variables. Table 5 shows the results of the cross-sectional dependence test (CDS), which indicates the presence of cross-sectional dependence. Consequently, the null hypothesis of no cross-sectional dependence is rejected, and the alternative hypothesis is accepted, confirming CSD at the 1% significance level.

Table 4 Panel unit root test

	Variables	LLC	ADF	PP
At level	CO2	-0.6666	70.5434	70.8679
	LICCCMT	-1.48335	62.9765	90.4251
	LDICCMT	6.84847	6.32786	7.15591
	Exp	10.7059	1.4782	1.10587
	FDI	3.99216	14.3094	11.2571
	GDP	11.5836	2.19821	3.28048
	Imp	15.0294	0.4848	0.14715
	LNRR	-4.11588	79.1473	122.777
	LREC	9.75555	2.48377	1.8833
1st difference	CO2	0.44721	232.901	491.203
	LICCCMT	-14.896	440.439	687.327
	LDICCMT	-12.8145	-15.7782	636.018
	Exp	-12.2005	279.32	391.118
	FDI	-11.7257	337.001	965.82
	GDP	-13.102	231.792	360.201
	Imp	-11.4686	261.158	444.121
	LNRR	-15.3141	412.203	664.517
	LREC	-11.9358	325.492	577.561

Table 5 Cross-sectional dependence test

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	1675.72***	378	0.000
Pesaran scaled LM	47.197***		0.000
Pesaran CD	6.6313***		0.000

5.3. Panel Granger Causality test

Table 6 represents the outcomes from the panel Granger causality test. The outputs show various causal links between the variables. A one-way causality was found between LICCCMT and CO2 emissions confirming that LICCCMT affects CO2 emissions in the OECD countries. the results did not confirm any causal link between LDICCMT and LICCCMT. We found a one-way causality running from exports to LICCCMT indicating the exports can enhance the LICCCMT. Moreover, the outcomes did not confirm any causal relationship between LFDI and LICCCMT. A one-way causality running from GDP to LICCCMT shows that GDP can positively affect LICCCMT in the OECD countries.

The outcomes of Ordinary least squares (OLS) and panel dynamic GMM models are tabulated in Table 7. The dependent variable CO2 emissions show a negative and significant relationship with LDICCMT in the study panel. It shows that domestic innovation in climate change mitigation technologies has a substantial impact on CO2 emissions degradation. Similarly, results are confirmed by the panel dynamic GMM model. The relationship between CO2 emissions, exports, FDI, and GDP shows a positive and significant indicating that these variables can adversely affect climate mitigation. it is important to mention that there is mixed literature on the relationship between CO2 emissions, and imports. Both OLS and GMM models confirmed similar outputs between the variables

Table 6 Panel Granger causality

Null Hypothesis:	Obs	F-Statistic	Prob.	Causality
LCO2 does not Granger Cause LICCCMT	750	5.88288	0.0029	One-way
LICCCMT does not Granger Cause LCO2		1.45449	0.2342	
LDICCMT does not Granger Cause LICCCMT	655	1.37528	0.2535	No=causality
LICCCMT does not Granger Cause LDICCMT		1.98788	0.1378	
LEXP does not Granger Cause LICCCMT	750	3.59441	0.028	One-way
LICCCMT does not Granger Cause LEXP		0.89193	0.4103	
LFDI does not Granger Cause LICCCMT	654	0.42467	0.6542	
LICCCMT does not Granger Cause LFDI		0.50291	0.605	No-causality
LGDP does not Granger Cause LICCCMT	750	1.45539	0.234	One-way
LICCCMT does not Granger Cause LGDP		0.02609	0.9742	
LIMP does not Granger Cause LICCCMT	750	3.07023	0.047	One-way
LICCCMT does not Granger Cause LIMP		1.61528	0.1995	
LNRR does not Granger Cause LICCCMT	750	0.19092	0.8262	No-causality
LICCCMT does not Granger Cause LNRR		0.12922	0.8788	
LREC does not Granger Cause LICCCMT	750	8.73942	0.0002	One-way
LICCCMT does not Granger Cause LREC		0.28185	0.7545	
LDICCMT does not Granger Cause LCO2	655	4.2543	0.0146	One-way
LCO2 does not Granger Cause LDICCMT		3.19777	0.0415	

Table 7 OLS and Panel dynamic GMM

Variable	OLS		Panel dynamic GMM	
	Coeff.	t-statistics	Coeff.	t-statistics
LDICCMT	-0.031**	1.288	-0.032***	3.381
LEXP	0.930***	13.26	-0.048**	-2.201
LFDI	0.082***	3.957	0.013**	2.473
LGDP	0.725***	16.06	0.119***	4.616
LICCCMT	-0.156**	-2.383	-0.072***	-3.741
LIMP	-0.183***	-3.030	0.227***	10.75
LNRR	0.017***	3.306	0.056***	2.325
LREC	-0.202***	-10.03	-0.236***	-14.79
C	-1.824***	-4.067	-4.404***	-22.84
	Effects Specification			
Time effect	Yes		Yes	
Country effect	Yes		Yes	
R-squared	0.83		0.99	

Adjusted R-squared	0.82		0.99	
F-statistic	96.55			
Prob(F-statistic)	0.000		0.000	
Akaike info criterion		0.124		
Schwarz criterion		0.358		
Hannan-Quinn criter.		0.214		
Durbin-Watson stat		0.072 0.392		
Periods included: 31 Cross-sections included: 28				

*** represent significance at 10%, 5%, and 1% level, respectively.

5.4. Robustness test

The outcomes of the robustness test are presented in Table 8. A now common exercise in empirical studies is a "robustness check," where the researcher examines how certain "core" regression coefficient estimates behave when the regression specification is modified in some way, typically by adding or removing regressors [68]. Such exercises are now so popular that standard econometric software has modules designed to perform robustness checks automatically; for example, one can use the STATA commands check or check rob.

Table 8 Robustness test

Variable	**FMOLS**		**DOLS**	
	Coeff	t-statistics	Coeff	t-statistics
LDICCMT	0.044**	(3.082)	0.255***	(3.356)
LEXP	-0.085**	(-2.464)	-1.179***	(-3.329)
LFDI	0.024***	(2.993)	0.045895	
LGDP	-0.115***	(-2.948)	0.663***	(4.246)
LICCCMT	-0.093***	(-3.370)	0.308936	
LIMP	0.218***	(6.880)	1.764***	(4.927)
LNRR	0.006***	(1.920)	0.005*	(0.175)
LREC	-0.229***	(-9.920)	-0.306***	(-4.802)
R-squared	0.99		0.99	
Adjusted R2	0.99		0.99	
S.E. of regression	0.047		0.101	
Long-run variance	0.005		0.002	

*** represent significance at 10%, 5%, and 1% level, respectively.

6. Conclusion

The present study explores the relationship between CO2emissions, ICCCMT, GDP, DICCMT, REC, NRR, FDI, exports, imports for a panel of 30 OECD economies over the period of 1990-2020. The findings reveal that international collaboration in climate change mitigation technologies (ICCCMT) is a significant tool for CO2 mitigation's. Equally important, it can contribute to renewable energy consumption which has a negative relationship with CO2 in the OECD economies. Our study adopted various econometric techniques such as dynamic (GMM) and ordinary least square (OLS) that allows the data to be visually accessible and comprehensible. In particular, to check the robustness of the results, we used FMOLS and DOLS models to examine the outcomes of the main models. Thereby, our results from coefficient values are robust and consolidated as confirmed by the OLS and GMM models. We employ the second-generation econometric method to check cross-sectional dependency, stationary, and co-integration among variables.

Recommendations

Based on our findings, the study has a notable influence on the developing countries to enhance their share in clean energy consumption and learn from the industrial countries' mistakes in using extra fossil fuels. Consequently, countries with low carbon emissions could certainly adopt climate change mitigation technologies with efficiency improvements for stimulating their economic growth. Countries with fossil fuels dependency must acquire technology and enhance their domestic innovation. Regarding the present political risk and high uncertainty in many countries, we suggest an alert for global collaboration in terms of more transparency and purity to act towards limiting the increase of carbon emissions. Thus, tackling CO2 emissions via climate change mitigation technologies should be boundless and accessible. For this reason, mechanisms for facilitating technological access must be recapitulated by the Paris Agreement and outlined by countries' NDCs altogether for committing climate actions.

6.1. Future Work

This study employed a panel of 30 OECD countries. Future studies may consider other organizations and regions to investigate the impact of ICCCMT on carbon emissions. This will strengthen the significant impact of ICCCMT and propose new insights on mitigating CO2 emissions. The evaluation of technological progress along with environmental regulations must be considered to exhibit the abilities for international collaboration. In order to further analyze the impact of ICCCMT on CO2 emissions a more detailed empirical analysis regarding patents systems and commercialization, licenses, R&D implementation, and innovation will be crucial. In addition, including energy intensity, energy efficiency, and energy security in the study may also be consequential and may provide a noticeable contribution to the literature.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of ethical approval

Disclosure of conflict of interest as the corresponding author, I would like to declare that none of my co-authors nor I have any conflicts of interest that might affect the findings presented in this paper

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