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Investigation the Impact of Technological Innovation on Environmental Degradation: A Case Study of Developed Countries

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Abstract

Global warming is a hot and debatable issue among policymakers and researchers. Though several studies have explored the factors of environmental pollution by applying conventional and mean based estimation techniques, as well as the results of previous studies are mixed and inconclusive which demand further research on this issue. This research uses data from the Group of Seven (G-7) countries for the years 1996–2020 to examine the diverse effects of population, economic growth, technological advancements, and the use of renewable energy on CO_2 emissions. It applies several panel-sensitive and basic tests for analyzing the characteristics of the dataset. According to the results of the unit root tests, some variables are at first difference, while others are at level. We used the Johansen Fisher, and Kao cointegration tests; the findings of these tests confirm that all of the study's variables have a long-term relationship. Additionally, panel quantile regression is used, and the Jarque-Bera test's p-values are less than 0.05, rejecting the assumption of data normality. Because, in the case of data non-normality, the use of a linear regression model may provide mixed and inconclusive outcomes. Panel quantile regression results demonstrate that while population growth and economic expansion enhance environmental deterioration, technical innovation, and the use of renewable energy sources minimize environmental pollution. Based on the empirical findings, this study suggests policy implications for improving the environmental quality by reducing environmental degradation.

Keywords	Technological innovation, environmental degradation, economic growth

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INTRODUCTION

Environmental degradation is a notable menace that pervades worldwide and attracting the attention of researchers and policymakers. The dehumanizing effects of Environmental deterioration provokes greater thinking than terrorism or unemployment. The effects of environmental degradation have appeared in the form of floods, unpredictable rainfall amounts, melting glaciers, increasing ocean temperatures, rising sea levels, decreasing productivity of labor force, reduced agriculture output and decimated wildlife. Climate change is a major component of environmental degradation, climate change caused by greenhouse gases (GHG) and CO_2 emission is a significant factor which is responsible for climate change. According to British Petroleum Statistic, CO_2 emission is consist of almost 75% of total GHG emissions globally (BP-Statistics, 2021).

Over the last few decades, CO_2 emission is increasing sharply. According to the World Bank, the global CO_2 emissions has been increased from 20605 to 34306 million tons during 1990 to 2018 (World Bank, 2021). There is a trade-off exists between economic growth and environmental quality. Many nations rely on fossil fuels to supply their energy needs. As a result, academics and policymakers are increasingly interested in how economic and human activity affect CO2 emissions.

Technological innovation (TIN) is a major element to increase economic growth but its impact on environmental quality is still unclear. As the higher growth leads to increases in energy consumption which might be less environmentally friendly. On the other hand, if the process of innovation is energy efficient, then it could increase the environmental quality. Many researchers believed that TIN could be a useful tool for attaining sustainable development through replacing fossil fuels based polluted technologies with environment friendly ones. A rebound effect might be the aftermath of technological progress, when the process may not provide the desired results (Hopwood et al., 2005; Saudi et al., 2019; Dauda et al., 2019; Habibullah & Kamal, 2024). According to the researchers, the role of technological innovation cannot be disregarded in the process of green development. As technological innovation helps to improve the method of production and energy generation (Fernandez et al., 2018; Denial, 2023; Ayres et al., 2003). According to Masoudi et al. (2020), Zenios (2024), and Sharma & Das (2024) there have been recent demands for information about how technology advancements affect the condition of the environment. Cheng et al. (2019) explained that TIN lowers CE, which has a major impact on EQ. They emphasized that patents are useful for advancing the technology that reduces pollution.

A key component of increasing economic growth is technological innovation (TIN). Adopting energy-efficient methods also helps to save resources and improve the quality of the environment (Anwar et al., 2021c). According to Saudi et al. (2019), one of the main factors considered in achieving sustainable development is TIN. Hopwood et al. (2005), described that switching from fossil fuel-based to green technology might reduce CO2. Furthermore, TIN can improve industrial processes and hence environmental quality (Gozgor, 2017). Additionally, renewable energy, energy efficiency, electric vehicle development, and carbon capture technologies are all effective ways to lower CO2 (Foo and Tan, 2016; Ali & Audi, 2016; Kwon et al., 2017; Cheng et al., 2019; Ali et al., 2021; William, 2021; Kumar & Gupta, 2023; Jamel & Zhang, 2024). Many researchers claim that technological innovation

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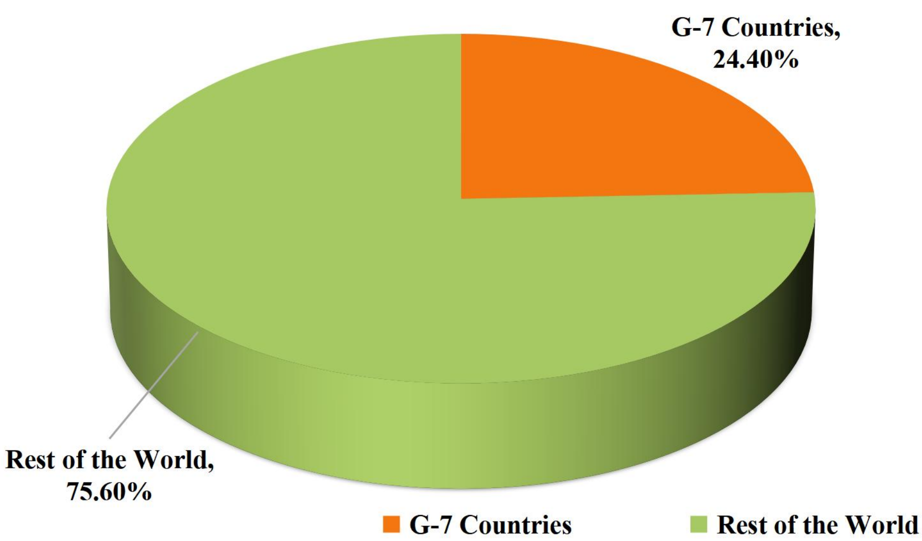
improves environmental quality. Governmental organizations, however, play a vital role in putting environmentally beneficial innovations into practice by enforcing environmental laws and regulations.
This research uses data from a group of seven (G-7) nations to examine how population, economic development, technical advancements and the use of renewable energy affect CO2 emissions. These seven nations are excluding over 24.4% of global CO2 emissions, according to BP-Statistics (2021), and their large CO2 emissions were the primary factor in choosing them for the current research.

Figure 1: Percentage Share of G-7 Countries in World's Total CO_2 Emissions



Developed by: Author.
Data Source: British Petroleum Satatitics, 2021

The G-7 nations' combined GDP was 38.46 trillion constant US dollars just before to the coronavirus epidemic in 2019 (World Bank, 2021). The latest International Energy Agency research states that the worrying trend of rising CO2 emissions necessitates immediate action to curb environmental damage (IEA, 2019). The most developed nations in the world are the G-7. According to the World Bank (2021), these nations account for over 10% of the world's population and nearly 45% of its GDP. Similarly, over 24.4% of global CO2 emissions come from G-7 nations (Figure 1) (BP-Statistics, 2021).

In terms of achieving Sustainable Development, the entire world is facing many issues and one of the major issues is environmental degradation. Global warming's dehumanizing effects on people are more interesting than issues like terrorism or unemployment. The effects of global warming have manifested as melting glaciers, rising sea levels, rising ocean temperatures, irregular rainfall patterns, driven out livestock, decreased agricultural production, and declining worker productivity. Thus, the ever-increasing negative consequences of environmental deterioration are extremely concerning for both present and future generations. Similarly, on the other side, extreme environment-related rules and regulations could

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increase the unemployment rate, reduce economic development, destroy competitiveness, and harm society. Thus, every country must adopt suitable measures and policies which helps increases both economic growth and environmental quality. For this purpose, this study investigates the impact of macroeconomic determinants on environmental degradation and attempts to put up a thorough policy plan for attaining sustainable development.

Review Of The Literature

This section delivers a brief overview of previous studies which provide the motivation for our study and for developing relevant hypotheses.

H1: Technological Innovation and Environmental Degradation Nexus

A crucial field of research for achieving sustainable development is the body of literature now available on technological innovation and CO2 emissions. This literature may be categorized into two main sections: the first discusses how technical innovation can support the growth of green or clean energy, and the second discusses how it can lower CO2 emissions. TIN is essential to the growth of green energy (Willy, 2018; Chen and Lei, 2018; Zhang & Wu, 2020). Sohag et al. (2015) examined the relationship between CO2 emissions, energy consumption, and technological innovation using the ARDL approach. According to them, technical advancements increase energy efficiency, which reduces CO2 emissions and the usage of energy derived from fossil fuels. Similarly, by using the data from Canada, Lantz, and Feng (2006) analyzed the role of technological innovation, population, and economic growth on CO_2 emissions during 1970-2000. They discovered that TIN impedes CO2 emissions while population and economic growth surges CO_2 emissions.

Further, by using the data from China from 2000 to 2011, Lin and Wang (2015) reported technological innovation and low carbon investment performs a vital role in falling CO_2 emissions. During 1973-1993 for 27 economies, Meliciani (2000) discovered that investment in TIN improves environmental quality. Jin et al (2017) scrutinized that technological improvement in the energy sector decreases CO_2 emissions. Additionally, they recommended that the government support technical innovation in the energy industry. For 28 OECD nations during 1990-2014, Mensah et al. (2018) investigated the influence of technological innovation on CO_2 emissions. They found that funding TIN reduced emissions. Danish et al. (2019) suggested that EG originates from industrialization, which rises fossil fuels (natural resources) use that increases CO_2 emissions. They underlined that TIN may assist make better use of natural resources.

Moreover, Cho and Sohn (2018) described that green technological innovation is a key source of mitigating CO_2 emissions. On the other hand, numerous studies provide evidence that technological innovation mitigates CO_2 emissions directly. For instance, Balsalobre-Lorente et al. (2018) inspected the link between technological innovations, renewable energy consumption, and CO_2 emissions for European Union (EU) countries during 1985-2016. Torvanger (1991) conducted a study on energy-related manufacturing sector CO_2 emissions by using the data of nine Organization for Economic Co-operation and Development (OECD) countries for the period from 1973-1987. From empirical outcomes, he found a significant reduction in energy-related CO_2 emissions in the manufacturing sector during 1973-1987. He documented that technological innovation is a major factor in the reduction of energy-related CO_2 emissions in OECD countries. Similarly, Carraro and Siniscaico (1994) concluded

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that technological innovation plays an important role in solving environment-related problems.

Ganda (2019) explored the relationship between research and technological innovation (by using three different proxies, development investment, patent applications, and the number of researchers) and CO_2 emissions. The results demonstrate that research and development investment reduce environmental pollution, whereas patent applications increase CO_2 emissions. The number of researchers has an insignificant impact on environmental degradation.

Mensah et al. (2019) investigated the impact of technological innovation on CO_2 emissions by using the data of OECD countries during the period from 1990-2015. They used interaction terms of patent applications and trademark applications as a proxy for technological innovation. From empirical results, they found that technological innovation reduces environmental degradation in OECD countries. Irandoust (2016) studied the impact of technological innovation, renewable energy consumption, and economic growth on CO_2 emissions. They discovered that there is a unidirectional causal relationship between TIN and CO2 emissions by using the Granger causality test.

Saleem et al. (2020) scrutinized the association between technological innovation, renewable energy consumption, and CO_2 emission for 10 Asian countries during the period from 1980 to 2015. The results of fully modified OLS demonstrated that technological innovation, renewable energy consumption, and financial development reduce environmental degradation. On the other hand, non-renewable energy consumption and trade openness increase environmental pollution. Kihombo et al. (2020) observed the link between technological innovation, economic growth, and CO2. After applying continuously updated bias-corrected and continuously updated fully modified techniques, they claimed that technological innovation reduces environmental degradation, and financial development increases the ecological footprint. They also claimed the existence of the EKC hypothesis.

Destek and Manga (2021) explored the relationship between environmental degradation and environmental-related technical developments, the financial development index, and the use of renewable and non-renewable energy. For this purpose, they used ecological footprint and CO_2 emissions as a proxy for Environmental degradation. According to the empirical results, environmental degradation is exacerbated by financial development and non-renewable energy consumption, whereas it is mitigated by environment-related technologies and renewable energy consumption. They used continuously updated and bias-corrected methods as well as continuously updated and fully modified methods. Khattak et al. (2020) discovered the relationship between environmental pollution and patent application in the case of BRICS economies from 1980-2016. They claimed that there is no opposite affiliation exists between TIN and CO2 in China, Russia, India, and South Africa. Whereas Khan et al. (2020) explored the negative association between CO_2 emissions and technological innovations for BRICS countries during 1985-2014 by using the augmented mean group technique.

Adedoyin et al. (2020) investigated the influence of research and development expenditure (technological innovations), renewable energy consumption, and economic growth on environmental degradation. They applied a fully modified ordinary least square and dynamic ordinary least square technique. The empirical findings demonstrate that whereas non-renewable energy usage has a favorable

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impact on environmental deterioration, research and development spending and renewable energy consumption have an inverse relationship. The results also provide evidence for the presence of the Environmental Kuznets Curve hypothesis in these 16 European countries.

H_2 = Economic Growth and Environmental Degradation

Chen and Lei (2018) examined the impact of economic growth, technological innovation, renewable energy consumption, and non-renewable energy consumption on CO_2 emissions by using the data of 30 countries with research backgrounds for the period from 1980-2014. They applied quantile regression and found that technological innovation negatively affects environmental pollution across all the quantiles (from 10^{th} to 90^{th}) except 10^{th} and 20^{th}. They also found that non-renewable energy consumption and economic growth increase whereas renewable energy consumption reduces the environmental deterioration across all the quantiles (10^{th} to 90^{th}).

Adedoyin et al. (2020) investigated the connection between economic growth, research and development expenditure, renewable energy consumption, non-renewable energy consumption, and ecological footprint for 16 European countries by using the fully modified and dynamic ordinary least square during 1997-2014. The empirical results showed that research and development expenditure and use of renewable energy lessen environmental degradation while promoting economic expansion and the use of non-renewable energy increase the environmental degradation in these 16 European economies.

By using a fully modified ordinary least square technique for 85 developed and developing economies, Bhattacharya et al. (2017) analyzed the impact of institutional quality, economic growth, and renewable and non-renewable energy consumption on CO_2 emissions. They found that economic growth, institutional quality, and renewable energy have a negative impact on CO_2 emissions. On the other hand, non-renewable energy has a progressive impact on environmental pollution. Wawrzyniak and Doryn (2020) investigated the impact of EG, institutional quality, fossil fuels energy consumption, renewable energy consumption, and FDI on CO_2 by using the data of 93 emerging economies during 1995-2014. The findings demonstrated that EG and IQ increase environmental pollution. Conversely, the interaction term of institutional quality and EG reduces environmental deterioration.

H_3: Renewable Energy Consumption and Environmental Degradation Nexus

Tang et al. (2021) scrutinized the association between institutional quality, EG, REC, human capital, and FDI in CO_2 emission for 114 countries from 1986-2015. They applied the GMM technique for this purpose and found that FDI and REC impedes environmental degradation. Moreover, human capital and institutional quality are useful indicators for reducing environmental degradation.

Usman and Jahanger (2021) explored the link between IQ, FDI, FD and trade openness on CO2. In doing so, they used the data of 93 economies and applied panel quantile regression (PQR). The empirical outcome of their study shows that institutional quality reduces environmental pollution in all the quantiles except the 90^{th} to 95^{th} quantiles. Furthermore, the findings also show that trade openness, energy use, and financial development all lower environmental quality. On the other hand, FDI improves the quality of the environment. The outcomes also support the existence of the EKC hypothesis in these 93 countries.

Yang et al. (2021) scrutinized the impact of technological innovation, economic growth, remittance inflows, financial development, energy consumption, and

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urbanization on ecological footprint by using the data of BRICS countries for the period from 1990-2016. For this purpose, they applied Dynamic Seemingly Unrelated Regression (DSUR) and interaction terms of remittance inflows with technological innovation and financial development. The empirical result showed that technological innovation reduces environmental degradation. Energy consumption, urbanization, and financial development increase the ecological footprint. On the other hand, the interaction term of remittance inflows and financial development, remittance inflows, and technological innovation reduces environmental degradation.

Omri and Tarek (2020) examined the impact of FDI and technological innovations on CO_2 of emerging economies. For this purpose, they used the GMM technique. They found that CO2 is negatively impacted by technological innovation and the interaction term between FDI and technological innovation.

Following the debate above, we concluded that it is still unclear and inconclusive how technology advancements and institutional quality affect the environment. Numerous research found a favorable correlation between carbon emissions and technological advancements for instance Ganda (2019) for OECD countries through applying GMM technique, Khattak et al. (2020) for BRICS by applying the Common Correlated Effects Mean Group method, Dauda et al. (2019) for MENA countries by using FMOL and DOLS techniques, Brandao et al. (2015) for BRICS countries by using FGLS technique, and Su and Moaniba (2017) for 70 countries by using GMM approach while numerous studies highlighted an inverse linkage between technological innovations and environmental degradation such as Saleem et al. (2020) for 10 Asian countries by using FMOLS technique, Omri and Tarek (2020) for 23 emerging economies by applying GMM approach, Mensah et al. (2019) for OECD countries by using Panel ARDL, and Khan et al. (2020) for BRICS countries by applying AMG technique. On the other hand, few studies claimed an insignificant association between technological innovations and environmental degradation, for instance, Dauda et al. (2019) for G-6 countries by applying the FMOLS approach, Brandao et al. (2015) for G-7 countries through applying the FGLS approach.

Similarly, numerous studies demonstrate a favorable correlation between environmental deterioration and institutional quality for instance, Nguyen et al. (2018) for 36 emerging economies by using the GMM technique, Chowdhury et al. (2021) for the panel of 92 countries, Charfeddine and Mrabet (2017) for 15 MENA countries by applying FMOLS and DOLS method, Sabir et al. (2020) for South Asian region by using ARDL approach, Wawrzyniak and Doryn (2020) for 93 developing countries, Le and Ozturk (2020) for 47 emerging market and developing economies and Obobisa et al. (2022) for 25 African countries through applying AMG technique whereas numerous studies showed a negative linkage between institutional quality and environmental degradation such as Bhattacharya et al. (2017) for 85 developed and developing countries through applying FMOLS approach, Danish et al. (2019) for BRICS countries by using DOLS technique, and Ali et al. (2020) for OIC countries by applying CSARDL .

Moreover, previous studies have used average-based econometric techniques, which cannot give a true picture when the data is not normal. Because of these conflicting and ambiguous results, the current study reexamined the relationship between technical advancements, institutional quality, and CO2 emissions by taking into account the effects of population, economic growth, and the use of renewable energy. The G-7 (group of seven) countries' data is used in this study for this purpose.

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This study recommends policy implications for G-7 countries which may be used as benchmark policies for developing and developed economies respectively.

Model Specification

To analyze the impact of anthropogenic activities on environmental quality, Ehrlich and Holdren (1971) established the IPAT (I=PAT).

The mathematical form of the above model is as:

$$I = P \times A \times T$$

Where I, P, A, and T are representing the environmental impact, population, affluence, and technology respectively. According to this model, the main factor behind environmental degradation is population. However, IPAT has a few drawbacks. Therefore, Dietz and Rosa (1997) modified this model as a stochastic model. After the modification, the new form of the model is STIRPAT or Stochastic Impacts by Regression on Population, Affluence, and Technology. The new form of the model is useful for statistical analysis. The new form of the equation is as,

$$I_i = a\, P_i^b\, A_i^c\, T_i^d\, e_i$$

In the above equation, I, P, A, and T are similar elements such as in IPAT model, however, a, is the constant, b, c, and d are the parameters that can be estimated using statistical tools.

This study estimates the following equations for empirical outcomes.

$$CE_{it} = \alpha_1 + \beta_1 EG_{it} + \gamma_1 TINit + \tau_1 REC_{it} + \upsilon_1 POP_{it} + \varepsilon_{1it} \qquad \textbf{(1)}$$

Where:

CE = CO_2 Emissions

EG = Economic Growth

TIN = Technological Innovations

Description Of Variables

CE: CO_2 emissions are used as a proxy for environmental degradation and measured as kilo tons of CO_2 equivalent.

EG: Economic Growth is measured with GDP per capita which is a proportion of the sum of a country's output (GDP) to the population of the country. The constant US dollar (2015) is a measurement scale of GDP.

TIN: Technology Innovation is measured with trademark applications by following the studies of Mensah et al., 2019; Erdogan et al., 2020; Anser et al., 2020.

REC: Renewable energy consumption is measured by the percentage share of total final energy use.

POP: Total number of Individual living in a country.

Average effects form the basis of the majority of classical regressions, which presume that the coefficient's influence is constant and does not vary over time for the whole population (Beyerlein, 2014). However, it is possible that the dataset contains outliers, in which case regression studies based on average impact may produce erroneous or misleading results. In this case, a more appropriate method that is not dependent on the mean value and can manage the problem of outliers is quantile regression (Canay et al., 2011; Waldmann, 2018).

Data Source

This research examines the effects of population, economic growth, technical advancements, institutional quality, and the use of renewable energy on CO2 emissions for the G-7 (Canada, Italy, Japan, the United Kingdom, the United States, France, and Germany) nations between 1996 and 2020. For this purpose, the present study collected the data of CO_2 emissions, GDP per capita, trademark applications,

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renewable energy consumption, and population from world development indicators of the World Bank (World Bank, 2021).

Results And Discussions

Descriptive Statistics

The data features of the current investigation are shown in Table 1. The outcomes show that the mean of CE, EG, TIN, REC, and POP are 13.56, 10.55, 11.30, 2.053, and 18.21. Likewise, the minimum and maximum values of CE, EG, TIN, REC, and POP are 12.61, 10.28, 10.39, -0.162, and 17.20 and 15.56, 11.01, 13.12, 3.121, and 19.61 respectively. The Jarque-Bera (J-B) test p-values, which are less than 0.05 and indicate that the data is not regularly distributed, are among the most significant findings in table 1. The application of linear regression in certain circumstances might yield deceptive results.

Table 1: Summary Statistics Of G-7 Countries

	CE	EG	TIN	REC	POP
Mean	13.56	10.55	11.30	2.053	18.21
Median	13.21	10.49	11.21	2.166	18.00
Maximum	15.56	11.01	13.12	3.121	19.61
Minimum	12.61	10.28	10.39	-0.162	17.20
Std. Dev.	0.883	0.177	0.701	0.790	0.652
Skewness	1.280	0.694	0.760	-0.815	0.785
Kurtosis	3.484	2.627	2.717	3.499	2.931
Jarque-Bera	49.53	15.08	17.44	21.21	18.02
Probability	0.000	0.000	0.000	0.000	0.000

Results Of Unit Root Test

The stationarity of the data must be verified prior to using the long-term estimation. Table 2 demonstrates the outcome of Im, Pesaran and Shin unit root test. The results reveal that CO_2 emissions, economic growth, and technological innovation are stationary at level with 1 percent level of significance and t-statistics values as -2.140, -1.912, and -1.638 respectively. Whereas the other variables as renewable energy consumption, and population are found to be stationary at 1st difference with 1 percent level of significance and t-statistics values as -7.780, and -2.474 respectively.

Table 2: Results Of Lm, Pesaran And Shin Unit Root Test

Variables	t-statistics	p-value	Order of Integration
	At Level		
CE_{it}	-2.140**	0.016	I (0)
EG_{it}	-1.912**	0.027	I (0)
TIN_{it}	-1.638**	0.050	I (0)
REC_{it}	-0.078	0.468	-
POP_{it}	3.586	0.999	-
	At 1st Difference		
CE_{it}	-10.10***	0.000	-
EG_{it}	-3.710***	0.000	-
TIN_{it}	-6.579***	0.000	-
REC_{it}	-7.780***	0.000	I (1)
POP_{it}	-2.474***	0.006	I (1)

*,**, and *** show significant levels at 10%, 5% and 1% respectively.

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Results Of Cointegration Tests

The findings of Johansen Fisher, and Kao's cointegration test are displayed in table 3. The presence of cointegration between the variables is confirmed by the significant p-values of Kao and Johansen Fisher.

Table 3: Johansen Fisher Panel Cointegration Test

Hypothesized No of CE(s)	Fisher Stat.* From max-eigen test	p-value	From trace test	p-value
None	160.0	0.0000	257.8	0.0000
At most 1	74.83	0.0000	127.2	0.0000
At most 2	40.23	0.0002	70.48	0.0000
At most 3	27.65	0.0158	41.38	0.0002
At most 4	16.56	0.2805	26.63	0.0215
At most 5	32.57	0.0033	32.57	0.0033
		Kao-cointegration Test		
			t-statistics	p-value
	ADF		-2.686852	0.0036

Source: Author's Estimations.

The J-B test's p-value suggested that the data wasn't distributed regularly. The application of linear regression in such a scenario with non-normal data might yield deceptive results. To solve the problem of data non-normality, we use panel quantile regression. We use quantile regression once the problem of data non-normality has been verified. The results are shown in table 4. The findings show that CE is positively impacted by economic growth across all quantiles (10th to 90th). This result is comparable to that of Anwar et al. (2021b), Chien et al. (2021), Audi et al., (2025), and Suki et al. (2020). This finding suggests that the seven nations in the group (G-7) have difficulty raising their individual EG rates. But except from EG, these countries are still not taking the appropriate steps to lessen environmental impact while doing so.

Table 4: Results Of Panel Quantile Estimations Of G-7 Economies

Variables	Values	Grid of Quantiles 0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
EG_{it}	Coeff.	0.288 ***	0.275 ***	0.303 ***	0.403 ***	0.680 ***	1.096 ***	1.232 ***	1.311 ***	0.630 ***
	Std. Er.	0.021	0.032	0.043	0.068	0.177	0.424	0.069	0.045	0.107
	t-Stat.	13.493	8.598	6.930	5.894	3.843	2.581	17.755	28.936	5.864
	Prob.	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000
TIN_{it}	Coeff.	-0.330 ***	-0.262	-0.146 ***	-0.149 ***	0.087	0.540 ***	0.453 ***	0.452 ***	-0.370
	Std. Er.	0.035	0.176	0.037	0.021	0.166	0.093	0.065	0.093	0.238
	t-Stat.	-9.423	-1.489	-3.943	-6.834	0.528	5.768	6.931	4.839	-1.548
	Prob.	0.000	0.138	0.000	0.000	0.598	0.000	0.000	0.000	0.123

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REC_{it}	Coeff.	-0.133 ***	-0.136 ***	-0.125 ***	-0.065 ***	-0.034 ***	-0.053	-0.001	0.020	0.297 ***
	Std. Er.	0.004	0.007	0.009	0.018	0.012	0.035	0.019	0.022	0.037
	t-Stat.	-29.158	-18.680	-12.654	-3.618	-2.836	-1.516	-0.082	0.911	7.971
	Prob.	0.000	0.000	0.000	0.000	0.005	0.131	0.934	0.363	0.000
POP_{it}	Coeff.	1.907 ***	1.817 ***	1.629 ***	1.550 ***	1.131 ***	0.491 ***	0.582 ***	0.548 ***	1.484 ***
	Std. Er.	0.044	0.265	0.065	0.035	0.255	0.128	0.070	0.104	0.201
	t-Stat.	42.397	6.854	24.804	43.996	4.436	3.835	8.251	5.251	7.367
	Prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

"***, ** and * represent significant level at 1%, 5% and 10% respectively

Environmental contamination is decreased by technological advancement in all quantiles (10th to 90th). This outcome confirms the G-7 nations' efforts to implement cutting-edge, environmentally friendly energy-based technology. The research conducted by Anwar et al. (2022), Godil et al. (2021), and Razzaq et al. (2021) supports these findings. However, there is little correlation between CE and institutional excellence.

Additionally, using renewable energy lowers CO2 emissions from the 10th to the 50th quantiles. This result benefits the G-7 nations and demonstrates how they are switching from fossil fuels to renewable energy sources in an effort to address the escalating emissions trends. because, in contrast to using fossil fuels, using renewable energy sources does not release the CE. These results are consistent with those of Sharif et al. (2019), Anwar et al. (2021a), and Cai et al. (2021). POP raises CO2 emissions through all quantiles, however (10th to 90th).

Conclusion

Researchers and lawmakers continue to debate and discuss the topic of global warming. This issue still needs to be addressed, even though a number of research have investigated the components of environmental contamination using traditional and average-based estimating methodologies. Using data from highly developed (G-7) nations for the years 1996–2020, this study examines the diverse effects of population, economic development, technical advancements and the use of renewable energy on CO2 emissions. In addition to panel quantile estimation, the current work uses a number of panel-sensitive and fundamental tests to examine the dataset's properties. The following is a list of the findings and policy implications for accomplishing SDGs 13 (Climate Change), 9 (Technological Innovations), 16 (Government Institutions), 8 (Economic Growth), and 7 (Green and Clean Energy):

Quantile regression's empirical results show that technological innovation has a negative impact on carbon emissions. Additionally, using renewable energy lowers carbon emissions in every quantile. Conversely, economic growth has a beneficial impact on carbon emissions in every quantile (10th to 90th). In a similar vein, environmental contamination is favorably impacted by the population across all quantiles (10th to 90th).

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Policy Implications

This research makes some policy recommendations for the group of seven nations based on the aforementioned result. This study suggests the following policy implications that the governments of the G-7 nations should implement in light of the findings of the G-7 countries. Since economic expansion has been shown to deteriorate environmental quality, the governments of the G-7 nations must rethink their growth plans in a way that is environmentally sustainable. In this sense, the industrial processes can be changed so that these countries can replace the conventionally unclean inputs with larger amounts of contemporary, cleaner ones. In order to diversify their energy sources, governments must also review their energy sector policies and implement new plans. As a result, the G-7 countries should avoid importing fossil fuels and reduce their reliance on domestic fossil fuel supply. Instead, more investments in these industries should be made in order to expand the renewable energy sectors in these countries.

To support innovations in technology, the G-7 nations ought to increase their individual R&D budgets. In addition to boosting economic expansion, investments in the development of green technologies would support the growth of the renewable energy industry, which would further lower CO2 emissions. Last but not least, the G-7 countries had to think about implementing pertinent measures to slow down their rates of population increase. This would lower demand for products and services and, in turn, significantly lower CO2 emissions brought on by production.

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