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Greening Growth in the Digital Age: The Role of Green Finance and ICT in Reducing Carbon Emissions in Developed Economies

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Abstract

The transition toward a low-carbon development requires economies to balance financial and technological advancement with the growing imperative of environmental sustainability. Despite increasing scholarly attention to green finance (GFI) and digitalization, their joint implications for carbon emissions, particularly in the context of economic growth (GDP), industrialization (IND), and trade openness (TO), remain insufficiently explored across developed economies. This study investigates the effects of GFI, ICT, GDP, IND, and TO on CO_2 emissions in 12 developed economies from 2015–2024. Using a balanced panel of 120 observations, the study applies second-generation panel diagnostic tests and PCSE as the main estimator, with FGLS used for robustness checks. The findings indicate that GFI, ICT, and TO significantly mitigate CO_2 emissions, emphasizing the potential of green financial development, digital transformation, and trade integration to enhance environmental sustainability. In contrast, GDP and IND are found to significantly raise emissions, signifying that conventional growth and industrial expansion continue to exert substantial environmental pressures. The FGLS results support these findings, although the positive effect of industrialization is no longer statistically significant. Collectively, the evidence underscores the importance of expanding green finance, accelerating digital transformation, and fostering environmentally responsible trade while instantaneously decoupling economic and industrial growth from carbon-intensive activities. These procedures can help developed economies strengthen their pathway toward sustainable development and long-term carbon neutrality.

Keywords: Green finance, ICT, CO_2 emissions, Economic growth, Industrialization, Trade openness, PCSE, Developed economies

1. Introduction

Climate change is a significant global issue with environmental and economic impacts beyond the national level (Benveniste et al, 2020; Benzie & Persson, 2019). Climate risks and extreme weather are putting governments under pressure to adopt low-carbon development policies as temperatures rise. The implementation of the SDGs, the Paris Agreement, and the European Green Deal has strengthened international efforts to reduce carbon emissions and archive carbon neutrality. These efforts have propelled the decline of carbon emissions to the top of the policy agenda and have placed greater focus on structural, technological, and financial concerns that can enhance environmental quality.

Financing is a most significant part of this transition. Green projects are likely to have greater uncertainty and larger financing requirements than conventional projects, and therefore have a financing needs gap. This crisis can be addressed by GF, which can direct funds toward renewable energy and other environmental improvements. It can also spur green technological advancement and redirect investments towards carbon-intensive sectors. The reduction of its carbon emissions is increasingly evident in empirical data (Ai & Yan, 2024; Bas Turk, 2024). In particular, Ma and

Fei (2024) demonstrate the role of GF in decreasing CO2 emissions intensity through green technological innovation (GTI) and the reallocation of capital to green activities.

Information and communication technology (ICT) is playing a growing vital role in improving environmental quality. Emissions can be minimised through digital technologies that increase production efficiency, information flows and resource allocation. ICT's environmental impact will depend on technological efficiency and infrastructure, the energy mix, and the country's circumstances, given that ICT requires energy. As a result, there are differing empirical findings across aspects of the relationship between ICT and economies (Ullah et al., 2023; Onyeneke et al., 2024). However, evidence from OECD countries shows that ICT reduces CO_2 emissions, especially when digital development goes hand in hand with cleaner energy use and improved technologies (Kim, 2022; Destek & Sinha, 2020). However, emissions are also affected by economic growth, IND, and TO through production, energy demand, and technological diffusion. Economic growth can increase environmental pressures through energy consumption, and trade can exert a scale effect and encourage the adoption of green technologies and more efficient production (Muhammad et al., 2025; Kasman & Duman, 2015).

The study analyzes the effects of GFI and ICT on CO2 emissions across 12 developed economies during 2015-2024. Although research on GF and ICT is proliferating, the literature often addresses either of these variables individually, or a single country, or provides an overall summary of the mixed environmental effects across different contexts and approaches. However, the joint impact on lnGDP, IND and TO is relatively understudied in developed economies. This paper aims to fill these gaps by applying 2nd-generation panel methods to estimate the effects of GF, ICT, lnGDP, IND, and TO on CO2 emissions, with the primary method based on the PCSE estimator and FGLS as a robustness check. This research makes three main contributions to the existing literature. First, it introduces a Green Finance Index (GFI), a more comprehensive indicator of green financial development than a single indicator. Second, it combines GF and ICT into a single environmental framework alongside GDP, IND, and TO, and generates new evidence from economies with relatively well-developed financial and digital infrastructure. Third, the empirical model explicitly accounts for key panel data problems (dependence across sections, slope heterogeneity, heteroscedasticity, and serial correlation), thereby yielding a more accurate and robust estimate of the association. Overall, the studies offer a more comprehensive understanding of the linkages between financial, technological, economic, industrial, and trade conditions and environmental outcomes in developed economies.

The rest of the paper is organized as follows. Section 2 contains literature review. Section 3 contains the data, variables, model specification, and empirical strategy. Section 4 discusses empirical results and interpretations. Section 5 reports conclusion and policy implications.

2. Literature review

2.1. Green Finance and Carbon Emissions

Green finance is an important means of transitioning to low-carbon development by directing financial resources toward renewable energy, clean technologies, and environmentally friendly investments. Theoretically, GFI can reduce emissions by facilitating access to funds for green projects and restricting funds for carbon-intensive projects. However, its success depends on the development of financial markets, environmental governance, technological capabilities, and tools for assessing green finance.

The empirical evidence overwhelmingly suggests that green finance and carbon emissions are negatively related. Al Mamun et al. (2022) analyzed 46 countries and found that green finance (green bonds) contributes to carbon emissions reduction in both the short and long term. Likewise, Alamgir and Cheng (2023) analyzed 67 countries that have issued green bonds and found that green bonds reduce carbon emissions, more so post-Paris Agreement. Saha and Maji (2025) also reported a negative association between green bonds and carbon emissions for 44 countries. The results are supported by more recent evidence. Ma and Fei (2024) found that green finance reduces carbon-emission intensity by encouraging green technological innovation and reallocating investment toward green activities. Similarly, Baştürk (2024) found that carbon emissions in the sample of 48 countries are significantly reduced by green finance. Safdar et al. (2026) also found that green finance has a carbon-reduction effect and exhibits spatial spillovers. Bhardwaj et al. (2025) also conducted a meta-summary of bibliometric studies, which revealed the increasing importance of green finance in carbon mitigation in both developed and developing economies. Although there is increasing evidence, much of the literature focuses on specific instruments that fall under the category of green bonds rather than on a broader assessment of green financial development. Furthermore, evidence from developed economies remains relatively weak. This study addresses this question by using a Green Finance Index (GFI) to investigate the impact of green financial development on CO_2 emissions in developed economies.

H1: Green finance development significantly lowers CO_2 emissions in developed economies.

2.2. ICT and Carbon Emissions

The environmental impact of information and communication technology (ICT) is controversial, as ICT can be carbon-reducing and carbon-increasing. The use of ICT can increase energy efficiency, optimize production and transportation, enable remote work, lower information costs, and enhance resource allocation. Freitag et al. (2021) and Zafar et al. (2026) highlighted how digital technologies can help substitute for some carbon-intensive activities and make them more environmentally efficient. Meanwhile, the growth of digital infrastructure has the side effect of increased electricity consumption, as it requires data centres, communication networks, servers and electronic devices to function. Environmental costs can also be incurred in the production and disposal of ICT equipment.

The empirical results of these competing mechanisms have been mixed. Some studies, such as those by Ito et al. (2025) and Sahid et al. (2025), have linked higher ICT development to increased energy use and environmental pressures. However, some studies indicate that ICTs can also help reduce emissions by decreasing energy consumption, improving production, and replacing energy-intensive processes. The relationship between ICT and emissions is multi-dimensional, as demonstrated by Onyeneke et al. (2024) and Zafar et al. (2025), who found that the environmental impact of ICT use depends on the type of ICT indicator used. Recent research by Calvino et al. (2025) also notes that digital transformation can have multiple impacts on the net zero transition, including energy efficiency and the carbon intensity of energy consumption.

The mixed evidence indicated that the environmental footprint of ICT use is highly context-specific and closely linked to countries' technological development and energy structures. The internet is more widely available in developed countries, and the study examines how internet use can reduce CO_2 emissions in these countries.

H2: ICT significantly reduces CO_2 emissions in developed economies.

2.3. Economic Growth and Carbon Emissions

The interplay between GDP growth and CO2 emissions is one of the most established issues in environmental economics. An increase in growth may increase production, consumption, and transport emissions due to increased energy demand. It has a strong connection with the so-called Environmental Kuznets Curve (EKC) hypothesis, which states that with an increasing level of development of an economy, environmental degradation can first rise, but then begin to decline as the level of development becomes very high, either due to cleaner technologies, structural change, or more effective environmental regulation.

Empirical evidence remains inconclusive, both nationwide and by stage of development. Kasman and Duman (2015) found a strong association among economic growth, energy consumption, trade, and CO2 emissions in European economies. As Aye and Edoja (2017) pointed out, the relationship between growth and emissions may vary with the degree of economic development, while studied by Shahbaz et al. (2017) on G7 countries only support the notion that environmental degradation may exhibit nonlinear correlations. More recent data still show that economic activity may put pressure on emissions, as more output remains reliant on carbon-intensive energy. Therefore, economic growth does not necessarily imply environmental enhancement even in developed economies. Since the economies under consideration in this paper are highly developed but energy-intensive, economic growth can still drive emissions up regardless of technological advancement and environmental controls. In line with that, the research hypothesis is that economic growth is a significant predictor of CO2 emissions.

H3: GDP exerts a significant positive effect on CO_2 emissions in developed economies.

2.4. Industrialization and Carbon Emissions

The relationship between IND and CO2 emissions is close, as IND, manufacturing, construction, mining, and related activities require substantial energy and material inputs. Growth in industrial manufacturing can lead to increases in fossil fuel consumption and electricity demand, as well as in transport-related and process emissions. But the environmental effects of industrialization are related to production technologies, energy efficiency, penetration of renewable energy sources, and environmental regulation.

Empirical studies have shown that CO2 emissions can increase during IND when it is based on traditional energy. Idowu et al. (2023) and Salahodjaev et al. (2023) investigated the concepts of industrialization and CO_2 emissions and revealed that renewable energy has a significant impact in reducing the environmental effects of industrialization. This means that industrial growth can no longer have the same environmental impact across countries; cleaner energy sources and more advanced production methods can reduce its carbon footprint. In the developed world, as Li & Xu (2020) observed, the emission intensities of some industrial activities have been reduced by improvements in energy efficiencies and cleaner manufacturing processes. But industrial production emissions can also be a significant source of total emissions. IND could be a source of environmental pressures, as the economies analyzed in this study have substantial industrial sectors, despite their technological levels. The research thus examines whether industry accounts for a larger share of economic activity and whether CO_2 emissions increase.

H4: Industrialization significantly increases CO_2 emissions in developed economies.

2.5. Trade Openness and Carbon Emissions

The impact of TO on CO2 emissions has not been clearly understood, either theoretically or empirically. There are scale, composition, and technique effects of trade upon environmental quality. The scale effect is the impact of increased trade on economic activity and energy demand, which may lead to higher emissions. The technique effect, on the other hand, signifies that international trade improves access to cleaner technologies, efficient intermediate inputs, and environmentally advanced production methods. The composition of trade is essential in determining the composition effect.

Empirical findings reflect these competing mechanisms. Gul et al. (2026) and Kasman and Duman (2015) found that trade plays an important role in explaining CO_2 emissions, while other studies by Herman & Xiang (2020) and Ikram et al. (2024) reported that greater trade openness can improve environmental quality through technological diffusion and efficiency gains. Evidence from developed economies is particularly relevant because stronger environmental regulation and greater technological capacity may allow countries to benefit from cleaner technologies obtained through international trade. However, trade may still increase emissions when it expands carbon-intensive production or shifts pollution-intensive activities across borders.

For the developed economies considered in this study, high technological capacity and strong integration into international markets may strengthen the technology and efficiency channels of trade. Therefore, this study examines whether greater trade openness is associated with lower CO_2 emissions after controlling for green finance, ICT, economic growth, and industrialization.

H5: Greater trade openness significantly reduces CO_2 emissions in developed economies.

3. Methodology

3.1. Data Source

This study employs a balanced panel of 12 developed economies (Australia, Canada, Denmark, France, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland, the UK, and the US) for the 2015–2024 period. The dependent variable is CO_2 emissions per capita ($lnCO_2$) from the World Development Indicators (WDI). The key variable is constructed as a Green Finance Index (GFI) using Principal Component Analysis (PCA), retaining components with eigenvalues greater than 1 and standardizing the first principal component for estimation. Other regressors are: GDP per capita (lnGDP), internet users (% of population, ICT), industrialization (industry value added, % of GDP), and trade openness (% of GDP), all from WDI. Table 1 summarizes the variables and their sources.

Table 1: Variable Description

Variable	Symbol	Measurements	Source
Carbon dioxide emissions	$lnCO_2$	per capita (t CO2e/capita)	WDI
Green finance index	GFI	Index (constructed from green bonds, sovereign green bonds, and renewable energy consumption)	Climate Change Dashboard (IMF) / WDI
Information and communication technology	ICT	Individuals using the Internet (% of population)	WDI
Economic growth	lnGDP	GDP per capita (constant 2015 US$)	WDI
Industrialization	IND	Industry, including construction, value added (% of GDP)	WDI
Trade openness	TO	Trade (% of GDP)	WDI

3.2. Model Specification

The study investigates the effects of GFI, ICT, GDP, IND, and TO on carbon dioxide emissions. The empirical interconnectedness is specified as follows:

$$lnCO_{2\mathrm{it}} = \beta_0 + \beta_1 GFI_{\mathrm{it}} + \beta_2 ICT_{\mathrm{it}} + \beta_3 lnGDP_{\mathrm{it}} + \beta_4 IND_{\mathrm{it}} + \beta_5 TO_{\mathrm{it}} + \varepsilon_{\mathrm{it}}$$

In this specification, I denotes country and t denotes time, whereas β_0 is the common intercept, β_1 to β_5 are the slope coefficients, and $\varepsilon_{\mathrm{it}}$ is the disturbance term. This specification corresponds to the reported panel estimations and does not impose country-specific fixed effects.

3.3. Empirical Strategy

Empirical analysis is conducted using a systematic sequence of econometric procedures to ensure reliable and robust estimation. First, descriptive data are presented on the overall behavior of the study variables and then the preliminary linear association between the study variables is assessed using pairwise correlation analysis. Then the VIF is computed to assess multicollinearity among the explanatory variables. Then, an analysis of the panel data's properties is conducted. In developed economies, where shocks and/or unobserved factors affecting one country may be transmitted to other countries, the CSD test is used to examine this possibility. The slope heterogeneity test is also conducted to assess possible differences in parameter estimates across countries. In addition, the modified Wald test is used to assess group-wise heteroscedasticity, and the Wooldridge test is used to assess first-order serial correlation. After these diagnostic procedures, the Pesaran Cross-Sectionally Augmented Im–Pesaran–Shin (CIPS) unit-root test is used to determine the stationarity properties and integration order of the variables, allowing for cross-sectional dependence. After the variables are determined to be integrated at levels or in first differences without exceeding first order, the Westerlund error-correction-based panel cointegration test is used to assess whether t stable long-run equilibrium relationship exists between the variables. The PCSE estimator is used with a common first-order autoregressive [AR (1)] error structure in the baseline estimation. This estimator is designed to cope with heteroscedasticity, contemporaneous correlation across cross-sections, and serial correlation, and produces more reliable standard errors and coefficient estimates for panel datasets with these features. The disturbance term is given by:

$$\varepsilon_{\mathrm{it}} = \rho\, \varepsilon_{\mathrm{i,t-1}} + u_{\mathrm{it}}$$

where ρ signifies the common 1^{st}-order autoregressive coefficient and u_{it} is the innovation term. In addition, FGLS is used as a robustness estimator to further assess the credibility of the baseline results. The common autoregressive error structure, cross-sectional units' contemporaneous correlation, and panel-specific heteroscedasticity can be addressed by FGLS. Thus, PCSE is the estimation method of choice, and FGLS is used as a robustness of the estimated relationships to an alternative estimation approach. The empirical procedures followed are summarized in the Stepwise Methodological Framework in Figure 1.

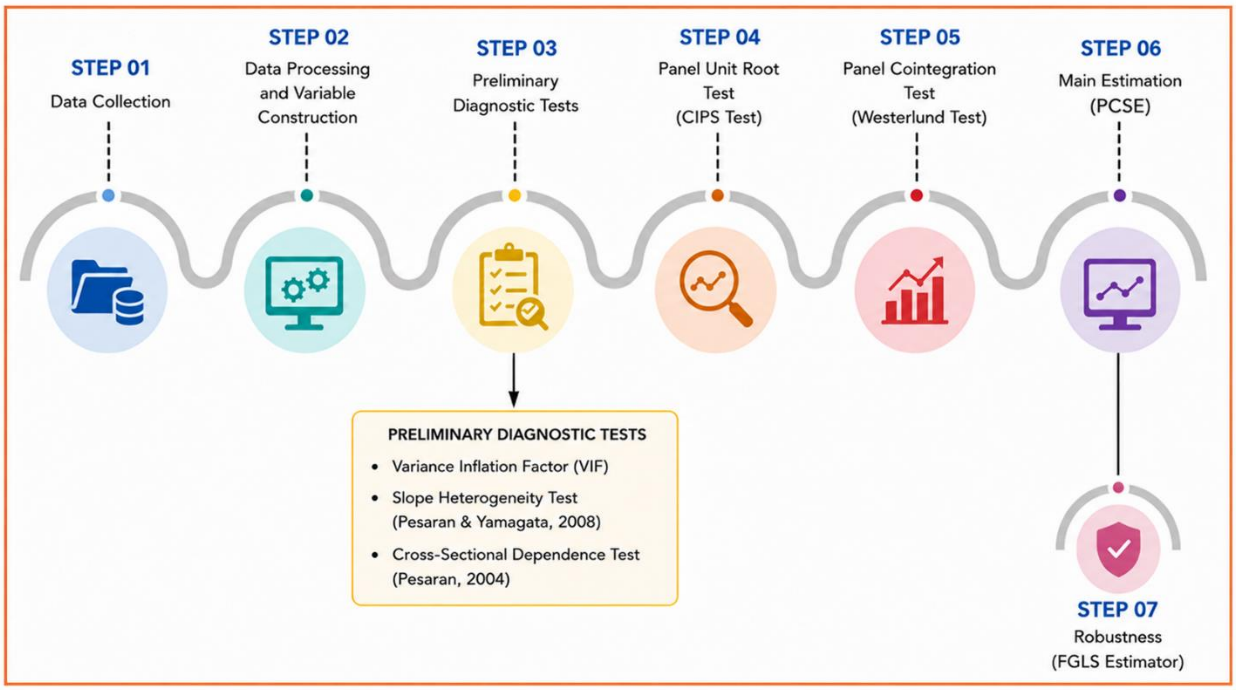

Figure 1: Presents the step-wise methodological framework of the study.

4. Results and Interpretation

The results of descriptive statistics report in Table 2 which indicates that $lnCO_2$ has a mean of 2.029 and a standard deviation of 0.494, while GFI averages 0.481 with moderately low variation. ICT records a high mean of 91.962%, reflecting strong digital penetration in the sampled developed economies, whereas lnGDP and IND average 10.876 and 23.066%, respectively. TO has a mean of 78.776% and the largest SD, indicating substantial variation in trade openness across the sample. Table 3 displays that GFI, ICT, lnGDP, and TO are negatively correlated with $lnCO_2$, while IND is positively correlated. Figure 2 display the scatterplot matrix, which visually supports these relationships and shows no excessively strong linear associations among the independent variables. The maximum correlation is between ICT and lnGDP, displaying no serious multicollinearity. This is further established by Table 4, where VIF values range from 1.24 to 1.53, with a mean of 1.36, well below conventional thresholds. Table 5 indicates that the adjusted Pesaran–Yamagata Delta test is significant ($p = 0.001$), indicating slope heterogeneity, while the Modified Wald test (χ^2 (12) = 438.92, $p < 0.001$) and Wooldridge test (F (1,11) = 141.152, $p < 0.001$) confirm group-wise heteroscedasticity and first-order serial correlation, respectively. Figure 3 further demonstrates the slope heterogeneity diagnostics through the bootstrap distributions of the Delta tests and the variation in estimated coefficients across cross-sections. Overall, these diagnostics confirm important cross-sectional differences and panel-data disturbances, supporting the use of an estimation approach that accounts for these characteristics.

Table 2: Descriptive Statistics

Variable	Obs.	Mean	S.D	Min	Max
$lnCO_2$	120	2.029	0.494	1.247	2.826
GFI	120	0.480	0.050	0.370	0.574
ICT	120	91.962	4.935	74.554	99.769
lnGDP	120	10.876	0.264	10.473	11.444
IND	120	23.065	5.399	15.769	47.867
TO	120	78.776	38.158	23.139	184.107

Table 3: Correlation Matrix

Variable	**$lnCO_2$**	**GFI**	**ICT**	**lnGDP**	**IND**	**TO**
$lnCO_2$	1.000					
GFI	−0.122	1.000				
ICT	−0.125	0.307	1.000			
lnGDP	−0.076	0.338	0.502	1.000		
IND	0.179	0.095	0.299	0.312	1.000	
TO	−0.478	0.334	0.330	0.256	−0.138	1.000

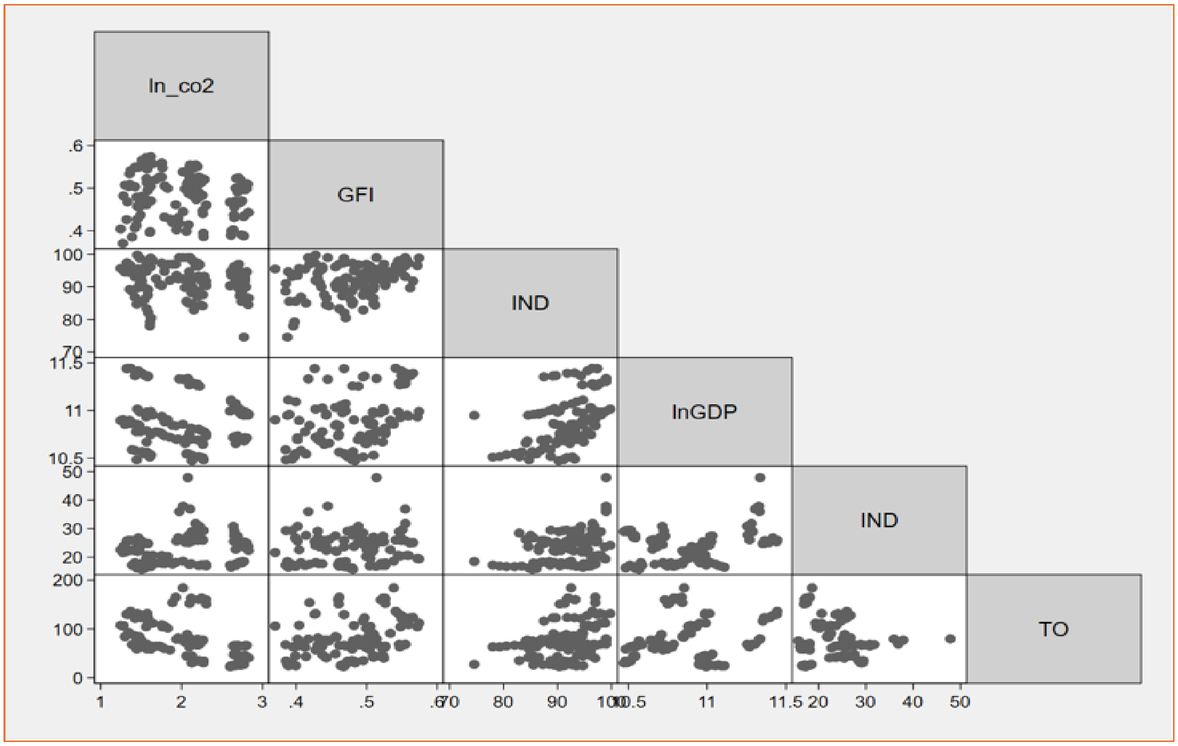

Figure 2: Scatterplot Matrix of the Study Variables.

Table 4: Variance Inflation Factor (VIF) Test

Variable	VIF	(1/VIF)
ICT	1.53	0.655
lnGDP	1.49	0.672
TO	1.32	0.757
IND	1.25	0.799
GFI	1.24	0.808
Mean VIF	1.36	—

Table 5: Slope Heterogeneity and Model Diagnostics

Test	Statistic	p-value	Decision / Interpretation
Pesaran–Yamagata Delta	1.889	0.059	Fail to reject homogeneity at 5%
Adjusted Delta	3.448	0.001	Reject homogeneity; slope heterogeneity exists
Modified Wald test	$\chi^2(12) = 438.92$	0.000	GroupWise heteroscedasticity exists
Wooldridge autocorrelation test	$F(1, 11) = 141.152$	0.000	First-order serial correlation exists

Note: The null hypothesis for the adjusted Delta test is homogeneous slope coefficients. The Wald and Wooldridge tests have null hypotheses of homoscedasticity and no first-order autocorrelation, respectively.

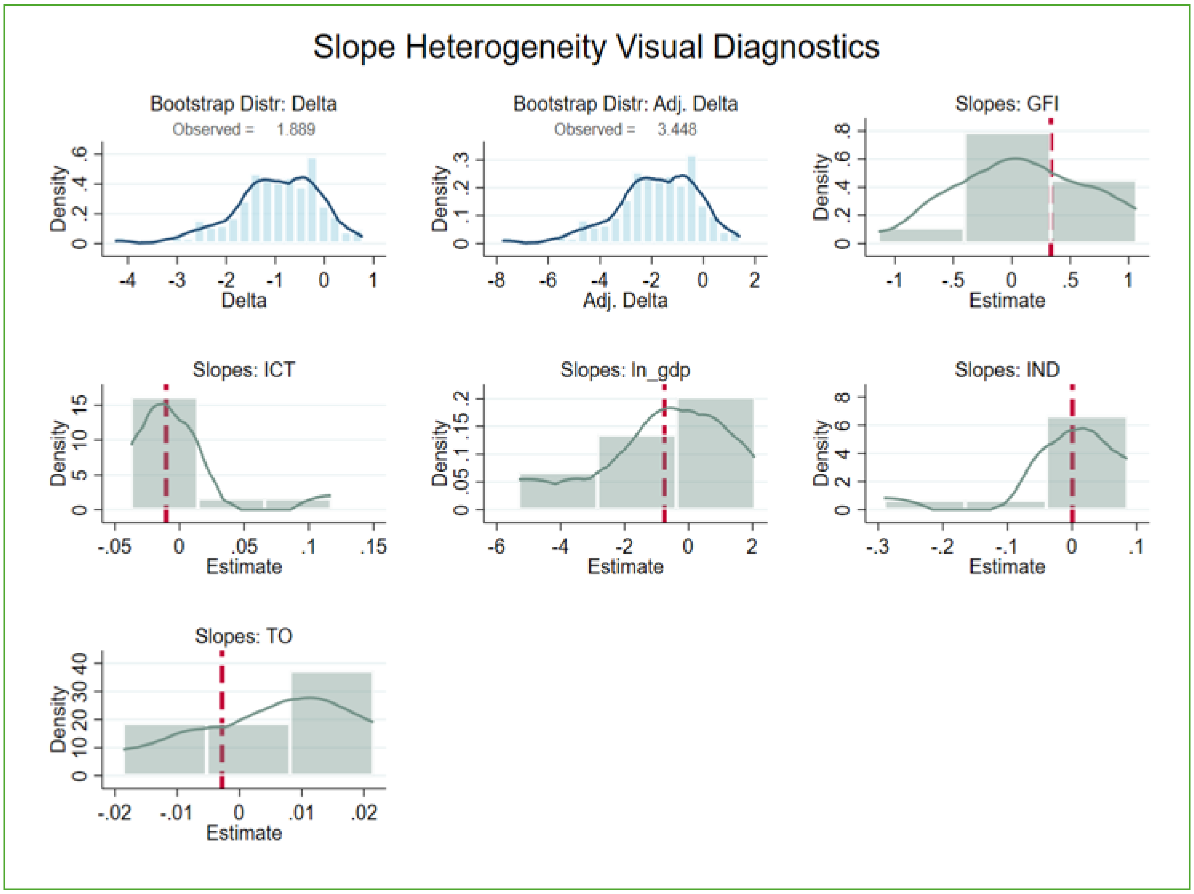

Figure 3: Slope heterogeneity diagnostics and coefficient distributions.

Table 6 reports the findings of CSD which indicate that all the variables are significant at the 1 percent level, showing that the null hypothesis of cross-sectional independence is rejected and that the sampled developed economies are sensitive to common economic, financial, technological, and environmental shocks. In view of this dependence, the second-generation CIPS test for unit roots is applied and presented in Table 7. The outcomes showed mixed ordered of integration, So, all variables are integrated at I (1) and I (0) but not at I (2). Moreover, the findings of Westerlund cointegration test reports in Table 8, which indicate that three of the four statistics reject the null hypothesis of no cointegration, providing evidence of a stable long-run relationship among the study variables. The analysis is therefore continued using PCSE to estimate the associations among the variables while accounting for panel-data disturbances.

Table 6: Cross-Sectional Dependence Test Results

Variable	CD statistic	p-value	Conclusion
$lnCO_2$	24.163	0.000	**CSD Exists**
GFI	23.924	0.000	
ICT	11.581	0.000	
lnGDP	22.264	0.000	
IND	12.160	0.000	
TO	15.311	0.000	

Table 7: Pesaran CIPS Panel Unit-Root Test Results

Variable	Level statistic	First-difference statistic	Order of integration
$lnCO_2$	-1.252	-6.013***	**Mixed Order of Integration**
GFI	-2.586***	-4.474***	
ICT	-1.954	-3.746***	
lnGDP	-3.218***	-6.173***	
IND	-1.945	-4.877***	
TO	−2.354	-3.867***	

Table 8: Westerlund (2007) Panel Cointegration Test Results

Test Statistic	Value	Z-value	P-value
Gt	-4.362	-2.875	0.002***
Ga	-12.717	0.484	0.687
Pt	-17.315	-10.959	0.000***
Pa	-18.917	-3.804	0.000***

*Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 9 reports PCSE results, which show the key estimates in this study. The model is statistically significant (Wald χ^2 (5) = 20.58) with a p-value (p = 0.001) and an $R^2 = 0.8711$, indicating that the explanatory variables account for 87.11% of the variation in CO_2 emissions. The AR (1) coefficient (ρ = 0.959) indicates strong persistence in the error process. Since there was evidence of CSD, heteroscedasticity, and serial correlation in the earlier evidence, PCSE is suitable for the main interpretation. The findings indicate that GFI has a significant negative effect on CO_2 emissions, meaning that the more developed it is, the lower the emissions. By encouraging the allocation of funds to sustainable investments, green finance can help minimize the need to invest in carbon-intensive activities and projects. The findings are consistent with Wang et al. (2021) and Baştürk (2024), which find that green finance helps reduce carbon emissions.

Similarly, ICT has a negative and statistically significant impact on CO_2 emissions. When other factors are held constant, there is an estimated 0.54% reduction in CO_2 emissions for every 1% increase in internet usage. Emissions can be reduced through digital technologies' contributions to energy and production efficiency, as well as resource management. This relationship is fairly universal and corroborated by Hubert & Le (2025) and Onyeneke et al. (2024), who demonstrated the significance of ICTs' role in environmental outcomes but noted varying impacts by the type of ICTs and country context. Moreover, the effect of lnGDP on CO_2 emissions is positive and statistically significant. This implies that economic growth is still putting pressure on the environment by increasing production, consumption, and energy demand. This result is aligned with Alajlan & Alreshaidi (2022), who found that economic growth positively affects CO_2 emissions. Moreover, IND has a positive effect on CO_2 emissions at the 10% level. Emissions rise by about 0.32% for every 1-percent rise in the industrial share of GDP. This indicates that industrial growth increases environmental pressures, including higher energy and carbon use in production, which calls for cleaner technologies and greater energy efficiency. The negative effect of TO is significant, indicating that an increase in TO reduces CO_2 emissions. Emission reductions of around 0.28% can be achieved by increasing trade openness by one percentage point. This could indicate the use of cleaner technologies, technology transfer, more efficient inputs, and cleaner production patterns in developed economies. This result aligns with Zhou et al. (2025). Overall, the PCSE results indicate that green finance, ICT, and trade openness decrease CO_2 emissions, while economic growth and industrialization increase them. Finally, the FGLS results broadly support the PCSE results: GFI, ICT, and TO are all negative and significant, while lnGDP is positive and significant. But IND is not significant ($p = 0.947$), indicating it is not robust to different estimators. Overall, the FGLS model is jointly significant ($p < 0.001$) and supports the main PCSE results.

Table 9: Panel-Corrected Standard Errors (PCSE)

Variable	Coefficient	Std. Error	p-value
GFI	−0.0045***	0.0013	0.001
ICT	−0.0054**	0.0025	0.032
lnGDP	0.4195*	0.2150	0.051
IND	0.0032*	0.0016	0.057
TO	−0.0027**	0.0014	0.049
Constant	−2.0514	2.4078	0.394
Model statistics: Observations = 120; groups = 12; $R^2 = 0.8711$; Wald χ^2 (5) = 20.58; Prob > χ^2 = 0.0010; common AR (1) coefficient (ρ) = 0.9590.			

*Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 10: Feasible Generalized Least Squares (FGLS) Results

Variable	Coefficient	Std. Error	p-value
GFI	−0.00241***	0.0009	0.009
ICT	−0.0042***	0.0005	0.000
lnGDP	0.5805***	0.0514	0.000
IND	0.00008	0.0013	0.947
TO	−0.0019***	0.0003	0.000
Constant	−3.8053***	0.5366	0.000
Model statistics: Observations = 120; groups = 12; periods = 10; Wald $\chi^2(5)$ = 250.33; Prob > χ^2 = 0.0000; common AR(1) coefficient (ρ) = 0.9788.			

*Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.*

5. Conclusion and Policy Implications

This study aims to examine how GFI, ICT, lnGDP, IND, and Trade openness (TO) affect CO_2 emissions across 12 developed economies from 2015 to 2024. The diagnostic test results indicated CSD, slope heterogeneity, heteroscedasticity, and serial correlation. In contrast, the unit root and cointegration results suggest that the variables are integrated and have a long-run relationship. Accordingly, PCSE is used as the main estimator, with FGLS as a robustness check. The outcomes of the PCSE show that green finance, ICT, and trade openness have significant negative effects on CO_2 emissions, while economic growth and Industrialization have significant positive effects. The FGLS estimates broadly support these results, except that Industrialization is not statistically significant. In summary, findings indicate that GFI and ICT can help reduce emissions. However, the process of economic and industrial growth still needs to be further de-linked from carbon-intensive activities. The results have two policy implications. Firstly, policy-makers need to reinforce green financing systems and focus more on renewable energy, clean technologies, and sustainable digital development. Increased issuance of green bonds, green loans, and sustainability-linked financing, with clear definitions and disclosure requirements, can ensure better financing for low-carbon activities. Combining the negative effects of green finance and ICT could further undermine emission reductions. Secondly, policies that focus on the economy and industry should prioritize cleaner growth, which means renewable energy, low-carbon technologies, and cleaner production processes. Trade policy can also support these actions by promoting access to cleaner technologies and inputs. Taken together, these can help developed economies find emissions-reduction solutions without sacrificing their competitiveness or their ability to achieve carbon neutrality.

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