



ENVIRONMENTAL DEGRADATION IN G7 COUNTRIES: THE ROLE OF ICT, INNOVATION, AND ENERGY TRANSITION

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Abstract

Introduction: Environmental degradation remains a critical challenge for G7 countries, despite their strong economic capacity, technological advancement, and climate commitments. This study examines environmental degradation productivity, measured by CO₂ emissions per unit of GDP, to capture the carbon intensity of economic output.

Methods: This study uses panel data from seven G7 countries during 2014–2023, with 70 country-year observations. The independent variables include Information and Communication Technology (ICT), industrialization, technological innovation, and renewable energy consumption. Panel data regression is applied, and the Random Effect Model is selected based on model specification tests.

Results: The findings show that ICT has a negative and significant effect on environmental degradation productivity, indicating that digital transformation supports environmental efficiency. Technological innovation has a positive and significant effect, suggesting a possible rebound effect. Industrialization has a positive but insignificant effect, while renewable energy consumption shows a positive and weakly significant effect.

Discussion: These results imply that reducing carbon intensity in G7 countries requires stronger digital integration, green-oriented innovation, industrial decarbonization, and deeper renewable energy substitution. General innovation and renewable energy expansion alone may not reduce environmental degradation unless they effectively replace carbon-intensive systems.

Keywords: ICT; Industrialization; Technological Innovation; Renewable Energy; Environmental Degradation

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A. INTRODUCTION

Climate change and environmental degradation remain among the most critical challenges facing the global economy. These issues require stronger collective commitment to achieving net-zero emissions and supporting the Sustainable Development Goals (SDGs) (Xu & Khan, 2023). In this context, the Group of Seven (G7) countries, consisting of Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States, have a strategic role in the global climate agenda. Although these countries represent only a relatively small share of the world's population, they continue to contribute substantially to global carbon dioxide emissions. In 2022, the G7 accounted for approximately 21% of global CO₂ emissions, making environmental mitigation and low-carbon transition in these countries essential for global climate stability (IEA, 2023).

This study focuses on environmental degradation productivity in G7 countries, measured by CO₂ emissions per unit of gross domestic product (CO₂/GDP). This indicator is important because it captures the carbon intensity of economic activities and reflects how efficiently a country generates economic output relative to the emissions produced. A lower CO₂/GDP ratio indicates better environmental efficiency, while a higher ratio suggests that economic growth remains dependent on carbon-intensive activities. Therefore, analyzing the determinants of CO₂/GDP is relevant for understanding whether advanced economies have successfully achieved decoupling between economic growth and environmental pressure.

Theoretically, the relationship between economic development and environmental quality is often explained through the Environmental Kuznets Curve (EKC). The EKC suggests that environmental degradation tends to increase at the early stages of economic development, but gradually decreases after countries reach a higher income level due to stronger regulation, cleaner technology, and greater environmental awareness (Grossman & Krueger, 1995; Uyi *et al.*, 2023). G7 countries are generally assumed to have entered the later stage of this curve. However, the persistence of carbon emissions indicates that high income alone does not automatically guarantee environmental improvement. Factors such as digital transformation, industrial structure, technological innovation, and renewable energy transition remain crucial in determining environmental outcomes.

Information and Communication Technology (ICT) plays a growing role in shaping environmental performance. In this study, ICT is used to represent the digital dimension of economic globalization because it supports cross-border information flows, market integration, digital connectivity, and global economic interaction. ICT may reduce environmental degradation through efficiency gains, smart production systems, digital monitoring, and lower transaction costs. Nevertheless, the environmental role of technology is not always straightforward. Technological innovation may reduce emissions when directed toward green technologies, but it may also increase energy demand and production scale when innovation is general-purpose. This condition is often associated with the rebound effect, where efficiency improvements are offset by higher consumption and output expansion.

Industrialization and renewable energy consumption are also central to environmental degradation in advanced economies. Although the G7 economies have shifted toward services and high-technology industries, industrial activity still contributes to energy use and carbon emissions. At the same time, renewable energy consumption is expected to reduce environmental degradation by replacing fossil fuels. However, its impact may remain limited when fossil fuels continue to dominate transportation, heavy industry, and other hard-to-abate sectors. This condition shows that the energy transition is not only related to increasing renewable energy use, but also to the extent to which renewable energy can effectively substitute fossil-based energy systems.

Previous studies have examined environmental degradation in G7 countries using total CO₂ emissions, energy consumption, economic growth, globalization, and innovation

variables. However, fewer studies simultaneously examine ICT, industrialization, technological innovation, and renewable energy consumption using CO₂/GDP as a carbon-intensity-based measure of environmental degradation productivity. The novelty of this study lies in its use of CO₂/GDP as a productivity-oriented environmental indicator and its simultaneous examination of digitalization, industrialization, innovation, and renewable energy consumption in the G7 context during 2014–2023. Specifically, this study aims to examine the effects of ICT, industrialization, technological innovation, and renewable energy consumption on environmental degradation productivity using panel data regression. The findings are expected to contribute to the literature on digital transformation, energy transition, innovation, and environmental sustainability in advanced economies. Practically, the results may provide insights for policymakers in designing integrated digital, industrial, innovation, and energy-transition policies to reduce carbon intensity and support net-zero emission targets in developed countries.

B. LITERATURE REVIEW

1. Environmental Kuznets Curve and Environmental Degradation Productivity

The Environmental Kuznets Curve (EKC) provides a theoretical basis for explaining the relationship between economic development and environmental degradation. The EKC hypothesis argues that environmental degradation tends to increase during the early stages of economic growth because countries rely heavily on industrial expansion, fossil energy consumption, and resource-intensive production. However, after reaching a certain income threshold, further economic growth may reduce environmental degradation due to stricter environmental regulations, higher public awareness, cleaner technologies, and structural transformation toward less carbon-intensive sectors (Grossman & Krueger, 1995; Uyi et al., 2023). In the context of G7 countries, the EKC framework is relevant because these countries are generally classified as advanced economies that have passed the early stage of industrialization and are expected to achieve decoupling between economic growth and carbon emissions. Therefore, environmental degradation productivity, measured by CO₂ emissions per unit of GDP, is an appropriate indicator to assess the carbon intensity of economic output.

2. ICT, Economic Globalization, and Environmental Degradation Productivity

Economic globalization can influence environmental quality through two main mechanisms, namely the Pollution Haven Effect and the Pollution Halo Effect. The Pollution Haven Effect occurs when economic integration encourages the relocation of pollution-intensive activities, whereas the Pollution Halo Effect occurs when globalization facilitates the diffusion of cleaner technologies, better management practices, and more efficient production systems (Copeland & Taylor, 2004; Tariq et al., 2024). In this study, Information and Communication Technology (ICT) is used as a proxy for the digital dimension of economic globalization because ICT facilitates cross-border information flows, digital connectivity, market integration, international transactions, and global economic interaction.

ICT may reduce environmental degradation productivity by improving energy efficiency, optimizing supply chains, supporting smart grids, reducing transaction costs, and encouraging digital-based economic activities. The relevance of ICT in improving organizational efficiency is supported by Mutiarni (2017), who explains that electronic data processing can strengthen information management and support more effective organizational activities. Digital applications can also support learning, feasibility analysis, and decision-making processes in institutional contexts (Mutiarni et al., 2022). In addition, technology governance in e-commerce is important for strengthening digital transformation, market connectivity, and business empowerment, especially in the context of MSME development (Zulfachry et al., 2026). Therefore, in developed economies such as the G7, mature digital infrastructure and

stronger environmental governance may enable ICT to reduce carbon intensity through more efficient production and consumption systems (Abid & Sekrafi, 2021; Tariq et al., 2024).

H₁: ICT, as a proxy for the digital dimension of economic globalization, has a negative effect on environmental degradation productivity in G7 countries.

3. Industrialization and Environmental Degradation Productivity

Industrialization is closely related to environmental degradation because industrial activities often require high energy consumption, resource extraction, and large-scale production processes. In the early stages of development, industrial expansion tends to increase carbon emissions because production relies heavily on fossil fuels and energy-intensive manufacturing. However, in advanced economies, the impact of industrialization may be different because industrial sectors are generally more technologically advanced, more regulated, and increasingly oriented toward cleaner production processes (Todaro & Smith, 2015; Gold & Tregenna, 2025).

In the G7 context, industrialization remains relevant because the manufacturing sector still contributes to economic output, even though these countries have experienced a structural shift toward services and high-technology industries. Industrial value added may still increase environmental pressure when industrial production depends on energy-intensive sectors. At the same time, sustainability-oriented investment has become increasingly important because environmental, social, and governance considerations are now part of investment decision-making and corporate responsibility (Cakranegara & Sidjabat, 2021). Therefore, although the effect may be weaker than in developing economies, industrialization is theoretically expected to increase environmental degradation productivity.

H₂: Industrialization has a positive effect on environmental degradation productivity in G7 countries.

3. Technological Innovation and Environmental Degradation Productivity

Technological innovation plays an important role in environmental transformation. Innovation may reduce environmental degradation when it is directed toward green technologies, renewable energy systems, energy efficiency, carbon capture, and low-carbon production. Green technology adoption can improve operational efficiency and stimulate value-added product innovation, showing that innovation may support business performance when it is integrated with environmental orientation (Wicaksono et al., 2026). However, technological innovation does not always produce environmental benefits. When innovation is general-purpose rather than specifically green-oriented, it may increase production capacity, stimulate consumption, and raise total energy demand. This condition is commonly explained through the rebound effect, where efficiency gains are offset by higher levels of economic activity and energy consumption (Tsvetkov & Andreichyk, 2025).

In this study, technological innovation is measured by the number of patents. This indicator captures general technological innovation and does not specifically distinguish between green patents and non-green patents. Therefore, a higher number of patents may reflect broader technological development that can increase economic activity and energy use, rather than directly reducing carbon intensity. In G7 countries, where innovation is highly advanced but not always fully oriented toward decarbonization, technological innovation may be associated with higher environmental degradation productivity if the innovation process is not sufficiently directed toward green transformation.

H₃: Technological innovation has a positive effect on environmental degradation productivity in G7 countries.

4. Renewable Energy Consumption and Environmental Degradation Productivity

Renewable energy consumption is generally expected to reduce environmental degradation because it substitutes fossil fuel use and supports the transition toward a low-carbon economy. A higher share of renewable energy in total energy consumption should theoretically reduce CO₂ emissions per unit of GDP by lowering dependence on coal, oil, and gas. Previous studies also emphasize the importance of renewable energy in mitigating ecological degradation and supporting carbon neutrality in advanced economies (Usman et al., 2021; Xu & Khan, 2023; Agbortoko Egbe et al., 2024).

However, the effectiveness of renewable energy consumption depends on the scale of adoption and the structure of the energy mix. In the G7 countries, renewable energy has increased, but fossil fuels remain dominant in several hard-to-abate sectors, such as transportation, heavy industry, and manufacturing. The circular economy perspective emphasizes the importance of resource efficiency, recycling, digital innovation, and sustainable business model transformation in supporting economic growth without worsening environmental pressure (Safariyani & Taufiqurrohman, 2023). Sustainability-oriented market behavior also shows that environmental awareness can influence business and consumer decisions, as reflected in studies on green products and environmentally friendly purchasing behavior (Hanifah et al., 2019). Therefore, although renewable energy consumption is theoretically expected to reduce environmental degradation productivity, its empirical effect may vary depending on the extent to which renewable energy actually substitutes fossil fuels.

H₄: Renewable energy consumption has a negative effect on environmental degradation productivity in G7 countries.

5. Conceptual Framework

Based on the EKC framework, Pollution Halo Effect, Pollution Haven Effect, rebound effect, and sustainability-oriented business literature, this study examines the effect of ICT, industrialization, technological innovation, and renewable energy consumption on environmental degradation productivity in G7 countries. ICT is expected to reduce environmental degradation productivity through digital efficiency and global connectivity. Industrialization is expected to increase environmental degradation productivity because industrial activities remain associated with energy use and emissions. Technological innovation is expected to increase environmental degradation productivity when innovation is general-purpose and not specifically directed toward green technology. Meanwhile, renewable energy consumption is expected to reduce environmental degradation productivity through fossil fuel substitution and low-carbon energy transition.

Conceptual Framework and Research Hypotheses

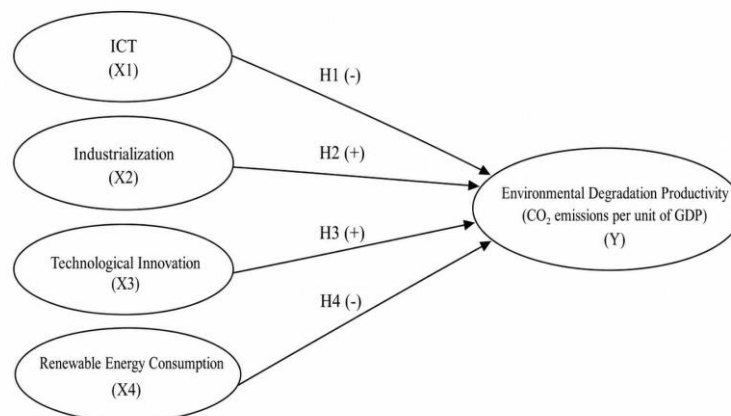


Figure 1: Conceptual Framework And Research Hypotheses

C. RESEARCH METHOD

This study employs a quantitative research approach using balanced panel data, which combines cross-sectional and time-series dimensions. The cross-sectional units consist of seven developed countries that are members of the Group of Seven (G7), namely Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. The time dimension covers the period from 2014 to 2023. Accordingly, this study uses 70 country-year observations. This period is selected because it captures recent developments in digital transformation, industrial activity, technological innovation, renewable energy transition, and environmental performance in advanced economies.

The dependent variable in this study is environmental degradation productivity, proxied by carbon dioxide emissions per unit of gross domestic product (CO₂/GDP). This indicator reflects carbon intensity in economic activities, showing the extent to which a country produces economic output relative to the carbon emissions generated. The independent variables consist of Information and Communication Technology (ICT), industrialization, technological innovation, and renewable energy consumption. ICT is used to represent digitalization and global economic connectivity. Industrialization is proxied by industrial value added as a percentage of GDP. Technological innovation is measured using the number of technology patents, while renewable energy consumption is measured as the share of renewable energy in total energy consumption.

The data used in this study are secondary data obtained from official international databases. Data on CO₂ emissions per unit of GDP and industrial value added are obtained from the World Bank and the International Energy Agency. ICT-related data are collected from the International Telecommunication Union. Patent data are obtained from the World Intellectual Property Organization, while renewable energy consumption data are derived from the International Energy Agency. All variables are transformed into natural logarithmic form to reduce data dispersion, stabilize variance, and allow the estimated coefficients to be interpreted as elasticities.

The operational definitions of the variables are presented in Table 1.

Variable	Symbol	Proxy / Indicator	Unit	Data Source	Rationale
Environmental Degradation Productivity	CO ₂ /GDP	CO ₂ emissions per unit of GDP	Metric tons of CO ₂ per GDP	World Bank; International Energy Agency	This indicator measures carbon intensity in economic activities and reflects environmental efficiency in producing economic output.
Information and Communication Technology	ICT	Percentage of internet users / ICT index	Percentage / index	International Telecommunication Union	ICT represents digitalization and global economic connectivity through information flows, market integration, and technology-based interaction.
Industrialization	IND	Industrial value added	Percentage of GDP	World Bank	Industrial value added reflects the contribution of industrial activity to national economic output.
Technological Innovation	INNOV	Number of technology patents	Number of patents	World Intellectual Property Organization	Patent data represent a country's capacity to produce and develop technological innovation.
Renewable Energy Consumption	REC	Renewable energy consumption	Percentage of total energy consumption	International Energy Agency	Renewable energy consumption reflects the progress of energy transition and the use of cleaner energy sources.

The empirical model is specified as follows:

$$\text{Ln}(\text{CO}_2/\text{GDP})_{it} = \beta_0 + \beta_1 \text{Ln}(\text{ICT})_{it} + \beta_2 \text{Ln}(\text{IND})_{it} + \beta_3 \text{Ln}(\text{INNOV})_{it} + \beta_4 \text{Ln}(\text{REC})_{it} + \mu_i + \varepsilon_{it}$$

Information:

$\text{Ln}(\text{CO}_2/\text{GDP})_{it}$ = natural logarithm of environmental degradation productivity in country i and year t

ICT_{it} = Information and Communication Technology in country i and year t

IND_{it} = industrialization in country i and year t

INNOV_{it} = technological innovation in country i and year t

REC_{it} = renewable energy consumption in country i and year t

β_0 = intercept or constant term

β_1 – β_4 = regression coefficients of the independent variables

μ_i = unobserved country-specific effect

ε_{it} = idiosyncratic error term

i = G7 member countries

t = observation year, 2014–2023

The estimation procedure applies panel data regression using three alternative models: the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM). Model selection is conducted through the Chow test, Hausman test, and Breusch-Pagan Lagrange Multiplier test. The Chow test is used to compare CEM and FEM, the Hausman test determines whether FEM or REM is more appropriate, and the Breusch-Pagan LM test examines whether REM is preferable to CEM. The final model is selected based on these diagnostic procedures.

To ensure the reliability of the estimation results, several diagnostic tests are conducted. The normality of residuals is examined using the Jarque-Bera test. Multicollinearity is evaluated through the correlation matrix among independent variables, with correlation values below 0.80 indicating the absence of serious multicollinearity. Heteroscedasticity is tested using a residual-based diagnostic test. Although Panel EGLS estimation can improve estimation efficiency, diagnostic tests are still reported to strengthen the validity of the empirical findings. All estimation procedures are conducted using EViews statistical software.

D. RESULTS AND DISCUSSION

This section presents the empirical findings of the study, which examine the effects of ICT, industrialization, technological innovation, and renewable energy consumption on environmental degradation productivity in G7 countries during the period 2014–2023. Environmental degradation productivity is measured by CO₂ emissions per unit of GDP. The analysis was conducted using panel data regression. Before estimating the final model, several model selection procedures were performed to determine the most appropriate panel estimation approach.

1. Panel Data Model Selection

Panel data estimation can be conducted using three alternative approaches: the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM). To identify the most suitable model, this study applied the Chow test, Hausman test, and Breusch-Pagan Lagrange Multiplier test. These tests are important because each panel model has different assumptions regarding individual country effects and their relationship with the explanatory variables.

The first step was the Chow test, which compares the Common Effect Model and the Fixed Effect Model. This test determines whether cross-sectional differences among G7 countries should be explicitly captured in the model.

Table 1. Chow Test Results

Effects Test	Statistic	df	Prob.
Cross-section F	1831.64	(6,59)	0.000
Cross-section Chi-square	366.277873	6	0.000

Source: EViews output, processed by the authors.

The results in Table 1 show that the probability values of both the Cross-section F and Cross-section Chi-square are 0.000, which are below the 5% significance level. This indicates that the null hypothesis is rejected. Therefore, the Fixed Effect Model is more appropriate than the Common Effect Model. This result suggests that differences among G7 countries are statistically relevant and should be considered in panel estimation.

After the Chow test indicated the relevance of the Fixed Effect Model, the next step was the Hausman test. This test was used to determine whether the Fixed Effect Model or Random Effect Model provides a more appropriate estimation.

Table 2. Hausman Test Results

Test Summary	Chi-Sq. Statistic	Chi-Sq. df	Prob.
Cross-section random	3.736183	4	0.4429

Source: EViews output, processed by the authors.

As shown in Table 2, the probability value of the Hausman test is 0.4429, which is greater than 0.05. This means that the null hypothesis cannot be rejected. Accordingly, the Random Effect Model is considered more appropriate than the Fixed Effect Model. This result implies that the unobserved country-specific effects are not significantly correlated with the explanatory variables.

To further confirm whether the Random Effect Model is preferable to the Common Effect Model, the Breusch-Pagan Lagrange Multiplier test was conducted. This test examines whether the variance of the random effect is statistically significant.

Table 3. Breusch-Pagan Lagrange Multiplier Test Results

Test	Cross-section	Prob.
Breusch-Pagan	246.6105	0.000

Source: EViews output, processed by the authors.

Table 3 indicates that the probability value of the Breusch-Pagan test is 0.000, which is lower than the 5% significance level. Therefore, the Common Effect Model is rejected in favor of the Random Effect Model. Based on the overall model selection process, particularly the Hausman and Breusch-Pagan Lagrange Multiplier tests, the Random Effect Model is selected as the most appropriate model for this study.

2. Random Effect Model Estimation Results

After the model selection tests were completed, the Random Effect Model was estimated using the Panel EGLS method. The estimation results are presented in Table 4. The table reports the coefficient, standard error, t-statistic, and probability value for each independent variable.

Table 4. Random Effect Model Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	325.229	113.416	2.86759	0.0056
ICT	-12.757	3.66231	-3.4833	0.0009
Industrialization	1.01576	1.05941	0.95879	0.3412
Technological Innovation	16.6581	5.65566	2.94539	0.0045
Renewable Energy Consumption	0.00967	0.00498	1.9414	0.0565
Adjusted R-squared	0.308038			
Prob(F-statistic)	0.000011			

Source: EViews output, processed by the authors.

The estimation results in Table 4 show that ICT has a negative and statistically significant effect on environmental degradation productivity. The coefficient of ICT is -12.757 with a probability value of 0.0009, indicating significance at the 1% level. This finding suggests that an increase in ICT is associated with a decrease in CO₂ emissions per unit of GDP in G7 countries.

Industrialization has a positive coefficient of 1.01576, but its probability value is 0.3412. This result indicates that industrialization does not have a statistically significant effect on environmental degradation productivity at conventional significance levels. Therefore, although the direction of the coefficient is positive, the effect is not strong enough to be interpreted as statistically significant.

Technological innovation has a positive and statistically significant coefficient of 16.6581, with a probability value of 0.0045. This indicates that technological innovation is positively associated with environmental degradation productivity at the 1% significance level. In other words, an increase in general technological innovation is associated with a higher level of CO₂ emissions per unit of GDP.

Renewable energy consumption also has a positive coefficient of 0.00967. However, its probability value is 0.0565. This means that renewable energy consumption is not statistically significant at the 5% level, although it is weakly significant at the 10% level. Therefore, this result should be interpreted cautiously. The positive coefficient indicates that renewable energy consumption has not yet shown the expected negative relationship with environmental degradation productivity in the G7 countries during the observed period.

The Adjusted R-squared value is 0.308038, meaning that approximately 30.80% of the variation in environmental degradation productivity can be explained by ICT, industrialization, technological innovation, and renewable energy consumption. Meanwhile, the probability value of the F-statistic is 0.000011, indicating that the independent variables jointly have a statistically significant effect on environmental degradation productivity.

3. Diagnostic Tests

To ensure that the estimation results are reliable, this study also conducted several diagnostic tests. These tests include the normality test, multicollinearity test, and heteroscedasticity test. Although the selected estimation model uses Panel EGLS, diagnostic testing remains useful to strengthen the validity of the empirical results.

a. Normality Test

The normality test was conducted using the Jarque-Bera method. This test was used to examine whether the residuals of the regression model are normally distributed. The results are presented in Table 5.

Table 5. Normality Test Results

Indicator	Value
Observations	68
Mean	1.39E-17
Median	0.004778
Maximum	0.153178
Minimum	-0.116141
Std. Dev.	0.058460
Skewness	0.255010
Kurtosis	2.980922
Jarque-Bera	0.738041
Probability	0.691411

Source: EViews output, processed by the authors.

Table 5 shows that the Jarque-Bera probability value is 0.691411, which is greater than 0.05. This indicates that the residuals are normally distributed. The skewness value of 0.255010 also shows that the residual distribution is relatively symmetrical, while the kurtosis value of 2.980922 is close to 3, which is consistent with the characteristics of a normal distribution.

b. Multicollinearity Test

The multicollinearity test was conducted using the correlation matrix among the independent variables. This test is important to ensure that the explanatory variables are not highly correlated with one another, as serious multicollinearity may distort coefficient estimates.

Table 6. Correlation Matrix

Variable	ICT	Industrialization	Technological Innovation	Renewable Energy Consumption
ICT	1.000000	-0.532680	0.429835	0.212946
Industrialization	-0.532680	1.000000	0.128088	0.037107
Technological Innovation	0.429835	0.128088	1.000000	0.078128
Renewable Energy Consumption	0.212946	0.037107	0.078128	1.000000

Source: EViews output, processed by the authors.

The results in Table 6 show that all correlation coefficients among the independent variables are below the threshold of 0.80. The highest correlation is between ICT and industrialization, with a value of -0.532680. Since this value is still below the critical limit, the model does not indicate serious multicollinearity problems. Thus, each independent variable can be retained in the regression model.

c. Heteroscedasticity Test

The heteroscedasticity test was conducted to examine whether the residual variance is constant across observations. A regression model is considered more reliable when it does not suffer from heteroscedasticity problems.

Table 7. Heteroscedasticity Test Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.39052	1.668533	-0.23405	0.815786
ICT	0.024412	0.025605	0.953387	0.344420
Industrialization	-0.23681	0.187581	-1.26244	0.211930
Technological Innovation	0.078406	0.111770	0.701491	0.485851
Renewable Energy Consumption	0.057163	0.140679	0.406336	0.686017

Source: EViews output, processed by the authors.

As shown in Table 7, all independent variables have probability values greater than 0.05. This indicates that the regression model does not suffer from heteroscedasticity. Therefore, the residual variance can be considered relatively constant, supporting the reliability of the estimation results.

4. Summary of Hypothesis Testing

Based on the Random Effect Model estimation, the results of hypothesis testing are summarized in Table 8. This table provides a concise overview of the direction, probability value, and decision for each proposed hypothesis.

Table 8. Summary of Hypothesis Testing

Hypothesis	Relationship	Coefficient Direction	Probability	Result
H1	ICT → Environmental Degradation Productivity	Negative	0.0009	Supported
H2	Industrialization → Environmental Degradation Productivity	Positive	0.3412	Not supported
H3	Technological Innovation → Environmental Degradation Productivity	Positive	0.0045	Supported
H4	Renewable Energy Consumption → Environmental Degradation Productivity	Positive	0.0565	Not supported at 5%; weakly significant at 10%

Source: EViews output, processed by the authors.

Table 8 shows that H1 and H3 are supported. ICT has a negative and significant effect on environmental degradation productivity, while technological innovation has a positive and significant effect. H2 is not supported because industrialization has a positive but statistically insignificant effect. H4 is also not supported at the 5% significance level because renewable energy consumption shows a positive coefficient, which is different from the expected negative direction. Although the coefficient is weakly significant at the 10% level, the result should be interpreted cautiously.

5. Discussion

The empirical results provide important insights into the determinants of environmental degradation productivity in G7 countries. Environmental degradation productivity in this study is measured by CO₂ emissions per unit of GDP, which reflects the carbon intensity of economic activities. The findings indicate that ICT has a negative and significant effect, technological innovation has a positive and significant effect, industrialization has a positive but insignificant effect, and renewable energy consumption has a positive coefficient that is weakly significant at the 10% level. These results suggest that environmental performance in advanced economies is influenced not only by the level of economic development, but also by the direction of digital transformation, industrial structure, innovation orientation, and the effectiveness of energy transition.

The results show that ICT has a negative and significant coefficient on environmental degradation productivity. This finding supports H1 and strengthens the argument that ICT, as a proxy for the digital dimension of economic globalization, can reduce carbon intensity in G7 countries. The result is consistent with the Pollution Halo Effect, which explains that digital connectivity and technology diffusion can improve energy efficiency, optimize supply chains, and strengthen environmental management. In developed countries such as the G7, digitalization supports smart grids, smart manufacturing systems, teleworking, digital monitoring, and economic dematerialization. These mechanisms reduce unnecessary energy use and shift economic value creation from energy-intensive physical production toward knowledge-based activities. This finding is in line with Tariq et al. (2024), who argue that green governance and green energy finance in G7 countries can be strengthened through digital tools, thereby helping to reduce carbon footprints.

The industrialization variable has a positive coefficient, but its effect is not statistically significant. Therefore, H2 is not supported. Although industrialization is theoretically expected to increase environmental degradation, the insignificant result indicates that industrial expansion in G7 countries does not strongly increase CO₂ emissions per unit of GDP during the observed period. This result can be explained by the post-industrial characteristics of the G7 economies. Most G7 countries have experienced a structural transformation toward service-

based and technology-intensive sectors, while their industrial sectors are subject to stricter environmental regulations and cleaner production standards. This finding is consistent with the Environmental Kuznets Curve perspective, which suggests that advanced economies may reduce the environmental burden of industrial activity through regulation, cleaner technology, and institutional capacity. It also aligns with Furtuna and Atis (2024), who explain that growth in high-income countries is increasingly driven by innovation and services rather than the expansion of conventional heavy industry.

Technological innovation has a positive and significant effect on environmental degradation productivity. This finding supports H3 and indicates that innovation does not automatically reduce environmental degradation. Although innovation is often expected to support energy efficiency and cleaner production, the patent-based innovation indicator used in this study captures general technological innovation, not specifically green innovation. Therefore, innovation may expand production capacity, stimulate consumption, and increase total energy demand. This result is consistent with the rebound effect, where efficiency gains are offset by higher output and energy consumption. The finding is also supported by Tsvetkov and Andreichyk (2025), who highlight that current climate policies often fail to fully address the need for transformative innovations that change production and energy systems. Thus, the positive coefficient suggests that G7 countries need to redirect innovation policies toward green technology, renewable energy systems, carbon capture, and low-carbon industrial transformation.

Renewable energy consumption has a positive coefficient and is weakly significant at the 10% level, but it is not significant at the 5% level. Therefore, H4 is not supported in the expected direction and should be interpreted carefully. This finding does not necessarily mean that renewable energy worsens environmental quality. Rather, it suggests that renewable energy consumption in G7 countries may not yet have reached a sufficient scale to fully replace fossil fuels. The dominance of fossil energy remains strong in transportation, heavy industry, and other hard-to-abate sectors. As noted by Agbortoko Egbe *et al.* (2024), developed countries still need to accelerate the energy transition and strengthen green energy finance to reduce carbon emissions effectively. In this context, renewable energy may increase alongside total energy demand instead of fully substituting fossil fuel consumption, which explains why its mitigating effect on CO₂/GDP has not yet appeared clearly.

Overall, the findings are consistent with the argument developed in the Introduction and Literature Review. ICT contributes to environmental efficiency through digital transformation and the Pollution Halo Effect. Industrialization no longer shows a strong direct effect because G7 economies have shifted toward cleaner and service-oriented structures. Technological innovation generates a positive effect because the innovation measured in this study is general innovation rather than specifically green innovation. Renewable energy consumption has not yet shown the expected negative effect because fossil fuel substitution remains incomplete. These results imply that reducing environmental degradation productivity in G7 countries requires an integrated strategy that combines digital transformation, green innovation, industrial decarbonization, and deeper renewable energy substitution. Policy efforts should therefore focus not only on increasing innovation and renewable energy use, but also on ensuring that innovation is environmentally oriented and that renewable energy effectively replaces fossil-based energy systems.

E. CONCLUSION AND RECOMMENDATIONS

This study examines the effects of ICT, industrialization, technological innovation, and renewable energy consumption on environmental degradation productivity in G7 countries during the period 2014–2023. Environmental degradation productivity is measured by CO₂ emissions per unit of GDP, which reflects the carbon intensity of economic activities. The

empirical results show that ICT has a negative and significant effect on environmental degradation productivity. This finding indicates that digital transformation can support environmental efficiency through better energy management, digital monitoring, smart production systems, and more efficient economic activities.

Technological innovation has a positive and significant effect on environmental degradation productivity. This result suggests that innovation in G7 countries has not fully contributed to carbon reduction, particularly when innovation is measured by general patent activity rather than specifically green innovation. Industrialization has a positive but statistically insignificant effect, indicating that industrial activities in G7 countries do not strongly increase CO₂ emissions per unit of GDP during the observed period. Meanwhile, renewable energy consumption shows a positive coefficient and is weakly significant at the 10% level, but not at the 5% level. Therefore, this result should be interpreted cautiously. It may indicate that renewable energy consumption has not yet fully substituted fossil energy in several key sectors.

Based on these findings, G7 countries need to strengthen policies that integrate digital transformation, green innovation, industrial decarbonization, and renewable energy transition. Policy efforts should not only increase the quantity of innovation and renewable energy use, but also ensure that innovation is environmentally oriented and that renewable energy effectively replaces fossil-based energy systems.

This study has several limitations. It only focuses on G7 countries and the 2014–2023 period. In addition, technological innovation is measured using general patent data, without distinguishing green patents from non-green patents. Future studies are recommended to include additional control variables, extend the observation period, compare developed and developing countries, and use more specific indicators of green innovation and renewable energy transition.

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