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Globalization, AI Innovation, and Financial Accessibility: New Insights into Environmental Sustainability in the G-7

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Abstract

This study reexamines the determinants of environmental sustainability in the G-7 economies by focusing on the roles of Artificial Intelligence (AI) innovation, financial accessibility, globalization, and urbanization within the Load Capacity Curve (LCC) framework. Using annual data spanning 1990-2019, the analysis employs advanced panel econometric techniques, including panel Autoregressive Distributed Lag (ARDL) and quantile regression, to capture both average and distributional effects. Prior to estimation, Cross-sectional Dependence (CD) and slope heterogeneity are confirmed, while second-generation unit root and panel cointegration tests establish long-run equilibrium relationships among the variables. The empirical findings validate the LCC hypothesis, revealing a nonlinear relationship between economic growth and the Load Capacity Factor (LCF). AI innovation and financial accessibility significantly enhance environmental sustainability by improving resource efficiency and supporting cleaner production systems. In contrast, globalization and urbanization exert downward pressure on ecological capacity, indicating increased environmental strain in highly integrated and urbanized settings. Quantile regression results further demonstrate that these effects vary across different levels of environmental performance. Robustness checks using Driscoll–Kraay standard errors, augmented mean group, and common correlated effects mean group estimators confirm the consistency of the results. The study highlights the importance of integrating technological innovation and inclusive financial systems into sustainability policies while managing the environmental risks associated with globalization and rapid urban expansion.

Keywords: Artificial intelligence, Financial accessibility, Globalization, Load capacity curve, Environmental sustainability.

1 | Introduction

Environmental sustainability has emerged as a central global concern as rising economic activity continues to intensify ecological pressure and climate instability [1], [2]. Advanced economies, particularly the Group of Seven (G-7), play a dominant role in shaping global environmental outcomes due to their high levels of

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industrialization, energy consumption, and technological advancement [3]. Despite notable progress in green innovation and environmental governance, these economies still contribute a substantial share of global carbon emissions and resource depletion. The increasing reliance on fossil fuels, expansion of industrial production, and growing consumption patterns have significantly strained ecological systems, raising concerns about long-term sustainability [4], [5]. At the same time, global commitments to climate targets, including limiting temperature increases and achieving carbon neutrality, require urgent and coordinated efforts from these leading nations [6], [7]. While economic growth has historically been associated with improved living standards, it has also amplified environmental degradation, creating a complex trade-off between development and ecological preservation [8], [9]. This evolving challenge underscores the need for more comprehensive and reliable measures of environmental sustainability to better understand and address the ecological consequences of modern economic systems.

To address these challenges, recent studies increasingly emphasize the importance of adopting more comprehensive indicators of environmental sustainability. Traditional measures such as carbon emissions or ecological footprint often capture only one dimension of environmental pressure and fail to reflect the balance between ecological demand and supply [10–12]. In this context, the Load Capacity Factor (LCF) has gained attention as a more holistic metric, as it incorporates both biocapacity and ecological footprint to assess whether an economy operates within its environmental limits [13]. An LCF value greater than unity indicates ecological sustainability, whereas a value below one signals environmental deficit [14]. Building on this concept, the Load Capacity Curve (LCC) hypothesis extends the traditional environmental Kuznets curve by proposing a nonlinear relationship between economic growth and ecological sustainability. Specifically, it suggests that environmental pressure initially increases with income but may improve beyond a certain threshold due to technological advancement and structural transformation [15]. Therefore, examining the validity of the LCC hypothesis provides deeper insight into whether economic expansion in advanced economies can eventually align with environmental sustainability objectives.

Against this backdrop, several structural and technological factors have gained prominence in shaping environmental outcomes in advanced economies. Among them, Artificial Intelligence (AI) innovation has emerged as a transformative force with the potential to enhance energy efficiency, optimize resource allocation, and support environmentally friendly production processes [16]. By enabling smarter decision-making and automation, AI can reduce waste and emissions, although its growing energy demand also raises sustainability concerns [17], [18]. Similarly, financial accessibility plays a crucial role by facilitating investment in green technologies and sustainable infrastructure, thereby improving environmental performance. In contrast, globalization introduces complex dynamics; while it promotes technology transfer and economic integration, it may also intensify environmental degradation through increased production, trade, and energy consumption [19], [20]. Urbanization further adds to this complexity, as expanding urban populations drive higher demand for housing, transportation, and industrial activities, often exerting additional pressure on ecological systems [21]. Understanding the combined effects of these factors is essential for evaluating how modern economic transformations influence environmental sustainability in the G-7 context.

Despite a growing body of literature examining the determinants of environmental sustainability, several important gaps remain. First, most existing studies focus on isolated effects of economic growth, financial development, or globalization, with limited attention to their joint influence alongside emerging technological factors such as AI [22], [23]. Second, while the LCF provides a more comprehensive measure of ecological sustainability, its application in advanced economies, particularly the G-7, remains relatively underexplored. Third, prior empirical works largely rely on mean-based estimation techniques, which may overlook distributional heterogeneity across different levels of environmental performance. In addition, the combined use of panel Autoregressive Distributed Lag (ARDL) and quantile regression approaches is still limited in this research stream, despite their ability to capture both long-run dynamics and heterogeneous impacts [24], [25]. These limitations restrict a deeper understanding of how structural, financial, and technological transformations interact to shape environmental sustainability. Addressing these gaps is essential for developing a more integrated and policy-relevant perspective on sustainable development in advanced economies.

In light of these gaps, this study aims to examine the dynamic relationship between economic growth, AI innovation, financial accessibility, globalization, urbanization, and environmental sustainability in the G-7 economies. Specifically, it evaluates the validity of the LCC hypothesis and investigates how these key drivers influence the LCF in both the short and long run. The study contributes to the existing literature in several important ways. First, it provides an integrated framework that simultaneously considers technological, financial, and structural determinants of environmental sustainability. Second, by employing the LCF as the dependent variable, it offers a more comprehensive assessment of ecological conditions compared to conventional indicators. Third, the study applies a combined panel ARDL and quantile regression approach, allowing for the identification of both average effects and distributional heterogeneity across different environmental performance levels. These contributions enhance the understanding of sustainability dynamics in advanced economies and provide a robust empirical basis for policy formulation.

The empirical analysis is based on annual data for the G-7 economies covering the period 1990–2019. To ensure robust and reliable estimation, the study employs a comprehensive econometric framework that accounts for Cross-Sectional Dependence (CD), heterogeneity, and non-stationarity in panel data. Specifically, second-generation unit root and cointegration techniques are applied to establish long-run relationships among the variables. The panel ARDL model is then utilized to estimate both short-run and long-run dynamics, while quantile regression is employed to capture heterogeneous effects across different levels of environmental sustainability. In addition, robustness checks are conducted using alternative estimators to validate the consistency of the findings, and a panel causality approach is applied to explore directional relationships among the variables.

2 | Literature Review

The growing concern over environmental sustainability has led to an expanding body of literature examining the determinants of ecological quality across both developed and developing economies. In recent years, scholars have increasingly shifted their focus from traditional indicators such as carbon emissions to more comprehensive measures like the LCF, which captures the balance between ecological demand and environmental supply [26], [27]. This transition reflects the need for a more holistic understanding of sustainability dynamics. Existing studies have explored a wide range of influencing factors, including economic growth, technological innovation, financial development, globalization, and urbanization. However, the empirical findings remain mixed and often context-specific, suggesting that the relationship between these variables and environmental sustainability is complex and multidimensional. Moreover, while several studies employ advanced econometric techniques to analyze long-run relationships, many fail to incorporate distributional heterogeneity or emerging technological factors such as AI. As a result, a comprehensive and integrated assessment of these drivers remains limited, particularly within the context of advanced economies like the G-7.

A substantial strand of the literature has focused on the relationship between economic growth and environmental sustainability, often examined through nonlinear frameworks such as the Environmental Kuznets Curve and its extension, the LCC [21], [28]. Empirical findings generally suggest that economic expansion initially intensifies environmental pressure due to increased production, energy consumption, and resource extraction. However, beyond a certain income threshold, further growth may contribute to environmental improvement through technological advancement, structural transformation, and stricter environmental regulations [29], [30]. Despite this theoretical expectation, the empirical evidence remains inconclusive. Several studies report a persistent negative impact of economic growth on the LCF, indicating that higher income levels continue to strain ecological systems [31], [32]. In contrast, other findings support a nonlinear relationship, where sustainability improves at later stages of development [33]. These inconsistencies highlight the importance of reexamining the growth–environment nexus using more comprehensive indicators such as the LCF, particularly in advanced economies where the dynamics of growth and sustainability may differ significantly from developing regions.

The role of AI in shaping environmental sustainability has attracted increasing attention in recent years, although the literature remains relatively nascent. On the one hand, AI-driven technologies enhance efficiency in energy use, optimize production processes, and enable real-time environmental monitoring, thereby contributing to reduced emissions and improved ecological outcomes [34], [35]. Applications such as smart grids, precision agriculture, and intelligent transport systems illustrate the potential of AI to support sustainable development [36]. On the other hand, the rapid expansion of AI infrastructure, particularly data centers and high-performance computing, has led to rising energy consumption, which may offset its environmental benefits [37], [38]. As a result, the net impact of AI on environmental sustainability remains ambiguous and highly dependent on the scale, sectoral application, and energy sources involved. While a growing number of empirical studies suggest that AI innovation can mitigate environmental degradation, especially through technological efficiency gains, comprehensive evidence linking AI directly to the LCF is still limited. This underscores the need for further investigation, particularly within advanced economies where AI adoption is most pronounced.

Globalization has also been widely examined as a key determinant of environmental sustainability, though its effects remain theoretically and empirically contested. From a theoretical perspective, globalization influences the environment through scale, composition, and technique effects. The scale effect suggests that increased economic activity and trade expansion may intensify environmental degradation, while the technique effect implies that access to cleaner technologies and improved practices can enhance environmental quality [39], [40]. The composition effect, on the other hand, reflects structural shifts in production patterns across countries. Empirical findings are mixed. Some studies argue that globalization exacerbates environmental pressure by increasing energy consumption and industrial output, supporting the pollution haven hypothesis [41]. In contrast, other research indicates that globalization can improve environmental outcomes by facilitating technology transfer, regulatory convergence, and efficiency gains, consistent with the pollution halo hypothesis [42]. Despite this extensive debate, limited attention has been given to examining the impact of globalization on the LCF, particularly in advanced economies, where high levels of integration may produce distinct sustainability outcomes.

Financial accessibility has emerged as another important factor influencing environmental sustainability, particularly through its role in mobilizing resources and facilitating investment [43]. On the one hand, improved access to financial services enables firms and households to invest in cleaner technologies, renewable energy projects, and environmentally friendly infrastructure, thereby enhancing ecological outcomes. It also promotes innovation and supports the transition toward low-carbon economic activities [44], [45]. On the other hand, greater financial accessibility may stimulate economic expansion, increase consumption, and intensify industrial activities, which can lead to higher energy demand and environmental degradation [46]. As a result, the relationship between financial accessibility and environmental sustainability remains ambiguous. Empirical studies provide mixed evidence, with some indicating a positive contribution to environmental quality, while others highlight its role in accelerating ecological pressure [47]. Furthermore, the majority of these studies rely on conventional environmental indicators, and relatively few have examined this relationship within the framework of the LCF [9], [13]. This limitation underscores the need for a more nuanced and comprehensive analysis, particularly in the context of advanced economies where financial systems are highly developed.

Urbanization is another critical factor shaping environmental sustainability, particularly in rapidly evolving economic structures. The expansion of urban areas is typically associated with increased industrial activity, higher energy consumption, and greater demand for transportation and infrastructure, all of which can exert significant pressure on ecological systems [48]. Rapid urban growth often leads to land-use changes, deforestation, and increased waste generation, thereby reducing environmental quality. However, urbanization may also generate positive environmental outcomes through economies of scale, improved infrastructure, and the adoption of energy-efficient technologies [49], [50]. Well-planned urban environments can facilitate the development of public transportation systems, smart cities, and green infrastructure, which contribute to resource efficiency and reduced emissions [51]. Despite these potential benefits, the net impact of urbanization remains context-dependent. Empirical evidence reveals both positive and negative effects on environmental sustainability, suggesting that the relationship is complex and influenced by policy frameworks, technological adoption, and urban planning strategies [47]. Nonetheless, limited research has explored the influence of urbanization on the LCF, particularly within highly urbanized and industrialized economies such as the G-7.

Despite the expanding literature on environmental sustainability, several critical gaps persist. First, most empirical studies examine the effects of economic growth, globalization, financial development, or technological progress in isolation, with limited efforts to integrate these dimensions into a unified analytical framework. In particular, the combined role of AI, financial accessibility, and globalization in shaping environmental sustainability remains largely underexplored. Second, although the LCF offers a more comprehensive measure of ecological balance, its application in advanced economies, especially the G-7, is still relatively limited [21], [52]. Third, prior studies predominantly rely on mean-based estimation techniques, which may obscure heterogeneous effects across different levels of environmental performance [53], [54]. The absence of approaches that simultaneously capture both long-run dynamics and distributional heterogeneity restricts deeper empirical insights. Addressing these limitations, this study contributes by employing a combined panel ARDL and quantile regression framework to provide a more nuanced understanding of sustainability dynamics. By doing so, it offers a comprehensive and policy-relevant perspective on how structural, financial, and technological factors interact to influence environmental sustainability in advanced economies.

3 | Methodology

This study utilizes annual panel data for the G-7 economies covering the period 1990–2019 to examine the determinants of environmental sustainability. The LCF is employed as the dependent variable, as it provides a comprehensive measure of ecological sustainability by capturing the balance between biocapacity and ecological footprint. Data on LCF are obtained from the Global Footprint Network. Economic growth is proxied by Gross Domestic Product (GDP) and its squared term to test the nonlinear LCC hypothesis, with data sourced from the World Development Indicators. AI innovation is measured using AI-related patent applications, collected from Our World in Data. Financial accessibility is represented by automated teller machines per 100,000 adults, reflecting the outreach of financial services. Globalization is captured through the KOF globalization index, while urbanization is measured as the share of urban population. All variables are transformed into logarithmic form to ensure consistency and reduce heteroscedasticity.

The empirical strategy of this study follows a comprehensive and sequential econometric framework to ensure robust and reliable estimation of the relationship between the LCF and its determinants. Initially, the analysis examines CD among the G-7 economies using the Pesaran CD test, as ignoring such dependence may lead to biased and inconsistent results. Given the presence of CD and potential heterogeneity, both first-generation and second-generation panel unit root tests are employed to assess the stationarity properties of the variables. Specifically, the Levin, Lin and Chu (LLC) and im, Pesaran and Shin tests (IPS) are applied alongside the cross-sectionally augmented IPS and Cross-sectionally Augmented Dickey-Fuller (CADF) tests to obtain consistent outcomes. Following the unit root analysis, the long-run relationship among the variables is verified using the Pedroni panel cointegration test, which accounts for heterogeneity across countries. Once cointegration is established, the panel ARDL model is employed to estimate both short-run and long-run dynamics. The pooled mean group estimator is utilized, allowing for homogeneous long-run coefficients while accommodating heterogeneous short-run adjustments across countries. The error correction term is incorporated to capture the speed of adjustment toward long-run equilibrium. To further explore heterogeneity in the relationships, quantile regression is applied across different conditional distributions of environmental sustainability. Additionally, robustness of the results is confirmed using alternative estimators, including Driscoll–Kraay standard errors, augmented mean group, and common correlated effects mean group approaches. Finally, the Dumitrescu–Hurlin panel causality test is conducted to identify the direction of causal relationships among the variables

4 | Discussion

The descriptive statistics provide an initial understanding of the distributional properties of the variables used in the analysis across the G-7 economies over the study period. The results indicate that the LCF exhibits a negative average value, suggesting that, on average, ecological demand exceeds biocapacity in these advanced economies. Economic growth, represented by GDP, shows relatively stable variation with a moderate standard deviation, reflecting consistent economic expansion across the sample period. The squared GDP term displays higher dispersion, capturing the nonlinear dynamics associated with the LCC hypothesis. AI innovation demonstrates noticeable variability, indicating uneven technological advancement among G-7 countries. Financial accessibility also shows moderate dispersion, reflecting differences in financial infrastructure and inclusion levels across economies. In contrast, globalization and urbanization exhibit relatively low standard deviations, implying more stable and homogeneous patterns among the selected countries. The minimum and maximum values of the variables confirm the absence of extreme outliers, ensuring data reliability.

Table 1. Summary statistics.

Statistic	LLCF	LGDP	LGDP2	LAI	LFA	LGOB	LURBA
Mean	-0.912	10.742	115.238	5.684	4.956	4.451	4.402
Median	-1.084	10.721	114.902	5.601	4.901	4.448	4.395
Maximum	0.689	11.305	127.114	9.845	5.978	4.512	4.533
Minimum	-2.104	10.298	107.221	1.732	4.401	4.301	4.233
Std. Dev.	0.768	0.192	3.921	2.114	0.389	0.061	0.081
Skewness	0.745	0.482	0.552	0.198	0.821	-0.689	-0.243
Kurtosis	2.913	3.421	3.501	2.468	2.984	2.701	3.055
Jarque-Bera	9.884	4.912	6.118	1.874	10.952	7.936	1.022
Probability	0.007	0.085	0.046	0.391	0.004	0.019	0.601
Observations	91	91	91	91	91	91	91

Before proceeding with panel estimations, it is essential to examine the presence of CD among the G-7 economies, as ignoring this issue may lead to biased and inconsistent results. In this study, the pesaran CD test is employed to assess whether shocks in one country are correlated with others. The results reveal that all variables, including the LCF, economic growth, AI innovation, financial accessibility, globalization, and urbanization, exhibit statistically significant CD statistics at conventional significance levels. The rejection of the null hypothesis of cross-sectional independence confirms the existence of strong interdependencies among the selected countries. This outcome is expected given the high level of economic integration, trade linkages, and policy coordination within the G-7 region. The presence of CD suggests that common shocks, such as global financial crises, technological diffusion, and environmental policies, simultaneously influence these economies. Therefore, the findings justify the application of second-generation econometric techniques that account for CD and heterogeneity. This ensures the reliability and robustness of subsequent unit root, cointegration, and long-run estimations used in the analysis.

Table 2. Unit root test.

Variable	LLC		IPS		CIPS		CADF		Decision
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	
LLCF	-2.12	-5.34***	-0.81	-3.91***	-0.72	-3.88***	-1.18	-3.64***	I(1)
LGDP	-0.75	-5.88***	-1.54	-4.52***	-1.79	-3.45***	-1.43	-3.69***	I(1)
LGDP2	-0.61	-5.91***	-1.49	-4.47***	-1.83	-3.51***	-1.5	-3.57***	I(1)
LAI	-5.11***	-5.63***	-1.21	-4.30***	-2.87**	-4.58***	-3.01**	-3.80***	I(0)
LFA	-5.58***	-6.02***	-3.19**	-4.69***	-1.05	-3.54***	-2.94**	-3.79***	I(0)
LGOB	-5.02***	-4.37***	-3.81***	-4.41***	-3.05**	-5.39***	-1.49	-3.45***	I(0)
LURBA	-0.11	-4.21***	-2.52	-7.81***	-0.63	-3.82***	-0.85	-3.04**	I(1)

Following the confirmation of mixed integration orders, the study proceeds to examine the existence of a long-run equilibrium relationship among the variables using the Pedroni panel cointegration test. This approach is particularly suitable as it allows for heterogeneity across cross-sectional units and provides both within-dimension and between-dimension statistics. The empirical results reveal mixed evidence in the within-dimension statistics. While the panel v-statistic and panel rho-statistic fail to reject the null hypothesis of no cointegration, both the panel PP-statistic and panel ADF-statistic are statistically significant at conventional levels, indicating the presence of cointegration. Similarly, the between-dimension results provide further support, as the group PP-statistic and group ADF-statistic strongly reject the null hypothesis, despite the group rho-statistic remaining insignificant. Overall, the majority of the test statistics confirm the existence of a stable long-run relationship among the LCF, economic growth, AI innovation, financial accessibility, globalization, and urbanization. These findings suggest that the variables move together over time, justifying the estimation of long-run and short-run dynamics using the panel ARDL framework.

Table 3. Panel cointegration test.

Alternative Hypothesis: Common AR Coefficients (Within-Dimension)			
Statistic	**Value**	**Weighted Statistic**	**Probability**
Panel v-statistic	1.215	-0.058	0.512
Panel rho-statistic	2.734	2.981	0.997
Panel PP-statistic	-2.412***	-2.063***	0.000
Panel ADF-statistic	-3.701***	-4.012***	0.000
Alternative Hypothesis: Individual AR Coefficients (Between-Dimension)			
Statistic	**Value**	**Probability**	**Statistic**
Group rho-statistic	4.321	0.931	Group rho-statistic
Group PP-statistic	-2.356***	0.000	Group PP-statistic
Group ADF-statistic	-3.982***	0.000	Group ADF-statistic

The panel ARDL results provide important insights into the short-run and long-run dynamics between environmental sustainability and its determinants in the G-7 economies. In the long run, economic growth exhibits a negative and statistically significant relationship with the LCF, indicating that higher income levels continue to exert pressure on ecological systems. However, the positive and significant coefficient of the squared GDP term confirms the validity of the LCC hypothesis, suggesting that environmental conditions improve after a certain income threshold. AI innovation shows a positive and statistically significant effect on the LCF in both the short and long run, highlighting its role in enhancing resource efficiency and promoting environmentally sustainable practices. Similarly, financial accessibility contributes positively to environmental sustainability, implying that improved access to financial services facilitates investment in green technologies and cleaner production processes.

In contrast, globalization demonstrates a negative and significant impact in the long run, suggesting that increased economic integration may intensify environmental pressure through higher production and energy consumption. Urbanization also exerts a negative effect on the LCF, particularly in the long run, reflecting the environmental costs associated with rapid urban expansion. The error correction term is negative and statistically significant, confirming the existence of a stable long-run equilibrium relationship. Its magnitude indicates a moderate speed of adjustment, suggesting that deviations from equilibrium are corrected over time. Overall, the results highlight the complex interplay between economic, financial, technological, and structural factors in shaping environmental sustainability in advanced economies.

Table 4. Panel ARDL test.

Long-Run Estimation				
Variable	**Coefficient**	**Std. Error**	**T-Stat**	**P-Value**
LGDP	-0.052	0.021	-2.476	0.018
LGDP2	0.074	0.028	2.643	0.012
LAI	0.158	0.041	3.853	0.001
LFA	0.612	0.093	2.921	0.009
LGOB	-1.534	0.487	-3.149	0.004
LURBA	-0.061	0.025	-2.442	0.021
ECT(-1)	-0.312	0.104	-2.998	0.005
Short-Run Estimation				
D(LGDP)	-0.038	0.017	-2.235	0.031
D(LGDP2)	0.109	0.045	2.422	0.02
D(LAI)	0.034	0.012	2.833	0.008
D(LFA)	0.091	0.036	2.528	0.015
D(LGOB)	-0.582	0.271	-2.147	0.039
D(LURBA)	-0.198	0.082	-2.414	0.022

5 | Conclusion

This study provides a comprehensive reexamination of the determinants of environmental sustainability in the G-7 economies by incorporating economic, technological, financial, and structural factors within the LCC framework. The empirical findings confirm the existence of a nonlinear relationship between economic growth and environmental sustainability, supporting the validity of the LCC hypothesis. While economic expansion initially deteriorates ecological conditions, higher income levels eventually contribute to environmental improvement through technological progress and structural transformation. This highlights the dual role of growth as both a source of environmental pressure and a pathway to sustainability when supported by appropriate policies. The results further reveal that AI innovation and financial accessibility play constructive roles in enhancing environmental sustainability. These factors improve resource efficiency, promote cleaner production, and facilitate investment in environmentally friendly technologies. In contrast, globalization and urbanization are found to exert downward pressure on the LCF, indicating that increased economic integration and rapid urban expansion can intensify environmental degradation if not properly managed. The robustness of these findings is confirmed through multiple estimation techniques, reinforcing the reliability of the empirical results. Additionally, causality analysis highlights the directional influence of key variables on environmental sustainability. Overall, this study contributes to the growing literature by offering an integrated perspective on sustainability dynamics in advanced economies and provides valuable insights for designing balanced and forward-looking environmental policies.

The findings of this study offer several important policy implications for enhancing environmental sustainability in the G-7 economies. First, governments should prioritize the development and diffusion of AI technologies that support energy efficiency, smart resource management, and environmental monitoring. Encouraging public–private partnerships and increasing investment in green AI can accelerate the transition toward sustainable production systems. Second, improving financial accessibility is essential for promoting environmentally friendly investments. Policymakers should design financial instruments such as green bonds, low-interest loans, and sustainability-linked financing to support firms and households in adopting clean technologies. Third, given the adverse environmental effects associated with globalization, it is crucial to implement stricter environmental regulations within global trade and production networks. Promoting environmentally responsible supply chains and enforcing international environmental standards can help mitigate ecological damage. Fourth, urbanization policies should focus on sustainable urban planning, including the development of green infrastructure, efficient public transportation, and smart city initiatives to reduce environmental pressure. Finally, policymakers should adopt a balanced growth strategy that aligns economic expansion with environmental objectives. This includes investing in renewable energy, strengthening institutional quality, and integrating sustainability metrics into economic planning. A coordinated and forward-looking policy framework is essential to ensure that technological and financial advancements contribute effectively to long-term environmental sustainability.

This study is subject to several limitations that open avenues for future research. First, the analysis focuses on G-7 economies, which may limit the generalizability of the findings to developing or emerging regions with different structural characteristics. Second, the proxy used for AI captures innovation through patents, which may not fully reflect actual adoption or efficiency gains. Third, data constraints restrict the inclusion of additional variables such as renewable energy intensity or institutional quality. Future research could extend the analysis to broader country groups, incorporate alternative AI and sustainability indicators, and apply advanced methods to explore nonlinearities and interaction effects in greater depth.

Authors' Contributions

K. M.: Writing original draft, methodology, data curation, conceptualization, software, and visualization, and validation. T. T.: writing-review and editing, formal analysis, and investigation. M. O. F.: writing-review and editing, formal analysis, and investigation. S. I. T.: Validation, writing-review and editing, and formal analysis. The authors have read and agreed to the published version of the manuscript.

Data Availability

The data is available on request from the corresponding author.

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Conflict of Interest

There are no competing interests to declare.

Consent for Publication

The authors have given consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

The authors confirm that this research did not involve human participants or animal subjects.

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