Transactions on Quantitative Finance and Beyond

www.tqfb.reapress.com

Trans. Quant. Fin. Bey. Vol. 3, No. 2 (2026) 100–110.

Paper Type: Original Article

Decoding Environmental Sustainability in Nordic Economies: The Interplay of AI Innovation, Banking Development, and Stock Markets

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Citation:

Received: 07 August 2025 *Revised: 24 September 2025* *Accepted: 02 January 2026*	Tasnuva, T., Mo, K., Farukh, M. O., & Tithi, S. I. (2026). Decoding environmental sustainability in nordic economies: The interplay of AI innovation, banking development, and stock markets. *Transactions on quantitative finance and beyond*, *3*(2), 100-110.

Abstract

This study examines the influence of Artificial Intelligence (AI) innovation on Ecological Footprint (EF) in the Nordic region, while accounting for the roles of Banking Development (BD), Stock Market Capitalization (SMC), economic growth, and urbanization over the period 1995–2021. Grounded in the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) framework, the analysis employs a panel econometric approach that incorporates cross sectional dependence and slope heterogeneity. Both first- and second-generation unit root tests confirm a mixed order of integration, justifying the application of the Panel Autoregressive Distributed Lag Model (Panel ARDL) to explore short run and long run dynamics. The empirical findings reveal that economic growth, SMC, and urbanization exert upward pressure on EF, indicating that expansion in economic and financial activities intensifies environmental stress in the region. In contrast, AI innovation and BD contribute to reducing ecological pressure, suggesting that technological advancement and financial intermediation can support environmentally sustainable outcomes. The error correction mechanism confirms a stable long run equilibrium relationship among the variables. Furthermore, causality analysis indicates directional linkages running from key explanatory variables to EF. The results highlight the critical importance of integrating digital innovation and sustainable finance strategies to achieve long term environmental sustainability in advanced economies.

Keywords: Artificial intelligence, Ecological footprint, Banking development, Stock market capitalization, Nordic economies.

1 | Introduction

Environmental degradation has emerged as one of the most pressing global challenges in recent decades, driven by rapid economic expansion, population growth, and intensifying resource consumption [1]. The

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https://doi.org/10.22105/tqfb.v3i2.86

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increasing demand for energy, coupled with industrialization and changing consumption patterns, has significantly amplified pressure on natural ecosystems [2], [3]. As a result, concerns surrounding climate change, biodiversity loss, and resource depletion have gained substantial attention among policymakers and researchers [4–6]. In this context, accurately measuring environmental sustainability has become critically important. While carbon emissions have been widely used as a proxy for environmental degradation, they often fail to capture the broader ecological pressure imposed by human activities [7], [8]. To address this limitation, the Ecological Footprint (EF) has gained prominence as a more comprehensive indicator, as it reflects the extent to which human consumption exceeds the regenerative capacity of the environment [9]. By incorporating multiple dimensions of resource use and environmental stress, the EF provides a more holistic understanding of sustainability challenges [10], [11]. Therefore, examining the determinants of EF is essential for designing effective policies aimed at achieving long term environmental sustainability.

The Nordic economies, comprising Denmark, Finland, Iceland, Norway, and Sweden, are widely recognized as global frontrunners in environmental sustainability and green transformation. These countries consistently rank among the highest in terms of human development, environmental performance, and institutional quality, supported by strong regulatory frameworks and proactive climate policies [12]. Their commitment to renewable energy adoption, carbon neutrality targets, and sustainable innovation has positioned them as role models in the global transition toward a low carbon economy [13], [14]. However, despite these achievements, the region faces a notable paradox. High income levels and advanced consumption patterns continue to exert considerable pressure on natural resources, potentially offsetting environmental gains [15], [16]. This creates a complex dynamic where economic prosperity and environmental sustainability coexist with underlying ecological stress. Moreover, the Nordic region's deep integration into global markets and its reliance on technologically intensive sectors further complicate this relationship [17]. As a result, examining the environmental consequences of economic and financial development within this context becomes particularly important. Understanding these dynamics can provide valuable insights into how advanced economies can balance growth with ecological sustainability.

In this context, several key factors have been identified as critical drivers of environmental sustainability, including economic growth, urbanization, financial development, and technological innovation. Economic expansion often intensifies resource utilization and energy demand, thereby increasing ecological pressure, although its impact may vary depending on structural and technological conditions [18]. Urbanization, while associated with improved infrastructure and efficiency gains, can also lead to higher consumption, waste generation, and environmental stress [19]. Financial development, particularly through banking systems and capital markets, plays a dual role by either facilitating environmentally harmful investments or promoting green financing and sustainable projects [20]. At the same time, technological advancement, especially in the form of Artificial Intelligence (AI), has emerged as a transformative force with the potential to enhance energy efficiency, optimize resource allocation, and support environmental monitoring [21], [22]. Within the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) framework, these factors represent the core dimensions of affluence and technology that shape environmental outcomes. Therefore, integrating these elements into a unified empirical framework is essential to better understand their combined influence on EF.

Despite the growing body of literature on environmental sustainability, several important gaps remain. A large share of existing studies has primarily relied on carbon emissions as the sole proxy for environmental degradation, which provides a limited view of ecological pressure [23], [24]. In contrast, the EF offers a more comprehensive assessment by capturing the overall demand on natural resources. Moreover, while financial development has been widely examined, most studies treat it as a single aggregate indicator, overlooking the distinct roles of banking systems and stock markets [25], [26]. The emerging role of AI in shaping environmental outcomes has also received limited empirical attention, particularly in advanced economies [27], [28]. In addition, prior findings on the environmental effects of financial development and technological progress remain mixed and often context dependent. Importantly, there is a scarcity of integrated analyses that simultaneously consider AI innovation, disaggregated financial development, and EF within the Nordic context. This lack of consensus and limited regional focus highlight the need for a more comprehensive and nuanced investigation.

2 | Literature Review

The measurement of environmental sustainability has evolved significantly in the empirical literature, with researchers employing a range of indicators to capture ecological degradation. Traditionally, carbon dioxide emissions have been the most widely used proxy due to their direct link with climate change and data availability [29]. However, this indicator provides only a partial view of environmental pressure, as it primarily reflects atmospheric pollution while neglecting broader resource use and ecosystem capacity [30]. In response to these limitations, the EF has emerged as a more comprehensive measure of environmental sustainability. It captures the total demand placed on natural resources by human activities, encompassing land use, energy consumption, and waste absorption relative to the Earth's biocapacity [31], [32]. As such, the EF offers a multidimensional perspective that aligns more closely with the concept of sustainable development. Recent studies increasingly adopt this indicator to better understand the balance between economic activities and environmental limits. Therefore, using EF as a proxy enables a more holistic assessment of sustainability and provides deeper insights into the drivers of environmental pressure [33], [34].

The relationship between economic growth and EF has been extensively examined in the literature, yet the findings remain inconclusive. A large body of empirical evidence supports the view that economic expansion increases ecological pressure through the scale effect, whereby higher income levels lead to greater consumption of energy and natural resources [35], [36]. This perspective suggests that sustained growth often intensifies environmental degradation, particularly in the absence of effective regulatory frameworks. Conversely, another strand of literature argues that economic growth can improve environmental quality over time through technological advancement, structural transformation, and improved environmental awareness, as reflected in the Environmental Kuznets Curve hypothesis [19], [37]. In this context, higher income levels may enable economies to invest in cleaner technologies and adopt more efficient production processes. However, empirical results vary significantly across countries and regions, indicating that the growth–environment nexus is highly context dependent. These mixed findings highlight the need for further investigation using broader sustainability indicators such as EF.

The role of AI in shaping environmental outcomes has attracted increasing attention in recent years, particularly as digital technologies become more integrated into economic systems. On one hand, AI is considered a powerful tool for promoting environmental sustainability by enhancing energy efficiency, optimizing resource allocation, and supporting real-time environmental monitoring [38], [39]. AI-driven applications can improve industrial processes, reduce waste, and facilitate the transition toward cleaner production systems. Additionally, smart technologies enabled by AI contribute to better urban management, efficient transportation systems, and improved energy consumption patterns [40], [41]. On the other hand, the rapid expansion of AI infrastructure, including data centers and computational processes, raises concerns regarding increased energy consumption and potential rebound effects [42]. This dual nature of AI suggests that its environmental impact is not straightforward and may vary depending on the level of technological advancement and policy support [43]. Despite its growing importance, empirical research examining the direct relationship between AI innovation and EF remains limited, especially in advanced economies.

The relationship between Banking Development (BD) and EF has been widely debated, with studies highlighting both beneficial and adverse environmental effects. On one hand, a well-developed banking sector can promote environmental sustainability by facilitating access to finance for green investments, renewable energy projects, and environmentally friendly technologies [44]. By channeling funds toward sustainable activities, financial institutions can play a crucial role in supporting the transition to a low-impact economy [45]. On the other hand, increased banking activities may stimulate consumption and industrial expansion through easier credit access, leading to higher energy demand and greater environmental pressure [46]. This expansionary effect can intensify resource use and contribute to ecological degradation, particularly in economies with limited environmental regulations. Empirical findings reflect this duality, with some studies reporting that BD reduces environmental pressure, while others indicate a positive association with EF [25], [47]. These contrasting outcomes suggest that the environmental impact of BD depends largely on the structure of financial systems and the extent to which sustainability considerations are integrated into lending practices.

The impact of Stock Market Capitalization (SMC) on EF has also received considerable attention in the literature, though the direction of its effect remains ambiguous. On one hand, the expansion of stock markets can stimulate industrial growth and large-scale investment activities, which may increase energy consumption and resource exploitation, thereby exerting upward pressure on EF [48]. Firms listed in active capital markets often prioritize profitability and expansion, which can intensify environmental degradation in the absence of strict environmental regulations [49]. On the other hand, well developed stock markets can facilitate the mobilization of capital toward environmentally sustainable projects, including renewable energy and green technologies [50], [51]. By improving transparency, corporate governance, and access to financing, capital markets can encourage firms to adopt cleaner production methods and sustainable business practices. Empirical evidence remains mixed, with some studies suggesting that stock market development exacerbates environmental pressure, while others indicate that it contributes to environmental improvement [52], [53]. These conflicting findings underscore the importance of examining this relationship within specific regional contexts.

3 | Methodology

This study utilizes balanced panel data for Nordic economies, including Denmark, Finland, Iceland, Norway, and Sweden, covering the period 1995–2021. The selection of countries is based on data availability and their relevance as advanced economies with strong environmental and financial systems. The EF is employed as the dependent variable to capture environmental pressure, measured in global hectares per capita. Data on EF are obtained from the Global Footprint Network. Economic growth is proxied by Gross Domestic Product (GDP) per capita (constant US dollars), while urbanization is measured as the share of urban population, both sourced from the World Bank database. BD and SMC are collected from the Global Financial Development Database. AI innovation is measured using AI related patent data from our world in data. All variables are transformed into logarithmic form to ensure consistency and reduce heteroskedasticity.

The empirical strategy is designed to ensure robust estimation of both short run and long run relationships among the variables while accounting for key panel data challenges. Initially, the presence of Cross-Sectional Dependence (CSD) is examined, as Nordic economies are highly integrated and may be influenced by common shocks. Ignoring this issue can lead to biased and inconsistent results [54]. Subsequently, the slope homogeneity test is conducted to determine whether the coefficients vary across countries, which helps in selecting an appropriate estimation technique. To assess the stationarity properties of the variables, both first- and second-generation panel unit root tests are applied, allowing for cross sectional dependence and heterogeneity. After confirming a mixed order of integration, the existence of a long run equilibrium relationship is verified using a panel cointegration test. Given these conditions, the Panel Autoregressive Distributed Lag Model (panel ARDL) is employed as the primary estimation technique. This approach is suitable for variables integrated of order zero and one and enables simultaneous estimation of short run dynamics and long run coefficients within a unified framework. The inclusion of the Error Correction Term (ECT) captures the speed of adjustment toward long run equilibrium. Finally, the Dumitrescu–Hurlin panel causality test is applied to identify the direction of causal relationships among the variables.

4 | Results and discussion

The descriptive statistics indicate moderate variation across the variables, with relatively low standard deviation values suggesting stable distributions over time. EF exhibits slight positive skewness, implying higher concentration around lower values with some extreme observations. Most variables show near-normal distribution, as supported by kurtosis values close to three. The Jarque–Bera statistics confirm normality for the majority of variables, except for EF and SMC, which show minor deviations. Overall, the data appear well-behaved and suitable for panel econometric analysis, providing a reliable basis for further empirical investigation.

Table 1. Descriptive statistics of variables.

Statistic	LEFP	LGDP	LAI	LBD	LSMC	LURBA
Mean	2.284	10.912	3.245	4.762	3.854	4.463
Median	2.031	10.925	3.281	4.781	3.902	4.458
Maximum	3.821	11.603	4.012	5.694	4.905	4.558
Minimum	1.642	10.214	1.845	3.912	2.451	4.341
Standard deviation	0.598	0.287	0.471	0.332	0.512	0.049
Skewness	1.214	-0.152	-0.438	-0.097	-0.721	0.062
Kurtosis	3.187	3.021	2.563	2.881	2.934	2.601
Jarque-bera	28.614	0.512	5.218	0.331	10.874	0.845
Probability	0.000	0.774	0.073	0.847	0.004	0.655
Observations	135	135	135	135	135	135

The CSD test results reveal that all variables exhibit statistically significant CD statistics at the 1% level. The corresponding p-values are consistently below 0.01, leading to the rejection of the null hypothesis of cross-sectional independence. This indicates that shocks affecting one Nordic country are likely to influence others, reflecting strong economic and financial integration within the region. Such interdependence is expected given the similar institutional frameworks and interconnected markets of these economies. Therefore, ignoring CSD could lead to biased estimates. These findings justify the use of second-generation econometric techniques that explicitly account for CSD.

Table 2. Cross-sectional dependence test results.

Variable	CD-Statistic	P-Value
LEFP	9.12***	0.000
LGDP	12.47***	0.000
LAI	5.98***	0.000
LBD	6.21***	0.000
LSMC	7.05***	0.000
LURBA	13.66***	0.000

The slope homogeneity test results indicate strong evidence against the null hypothesis of homogeneous slopes across cross-sectional units. Both the Delta and adjusted Delta statistics are statistically significant at the 1% level, as reflected by p-values of 0.000. This suggests that the relationship between the explanatory variables and EF varies across Nordic countries. Such heterogeneity may arise due to differences in economic structures, policy frameworks, and technological adoption levels. Therefore, assuming identical slope coefficients would be inappropriate. These findings justify the use of estimation techniques that allow for cross-country heterogeneity, ensuring more reliable and context-sensitive empirical results

Table 3. Slope homogeneity test results.

Test	Statistic	P-Value
Delta (Δ)	4.982***	0.000
Adjusted delta (Δ_adj)	5.764***	0.000

The panel unit root results indicate a mixed order of integration among the variables. Specifically, Log of Ecological Footprint (LEFP) and Urbanization (LURBA) are non-stationary at level but become stationary at first difference, confirming integration of order one. In contrast, Log of Gross Domestic Product (LGDP), Log of Artificial Intelligence (LAI), Log of Banking Development (LBD), and Log of Stock Market Capitalization (LSMC) are stationary at level across most tests. The consistency between first-generation (Levin, Lin and Chu test (LLC) and Im, Pesaran and Shin test (IPS)) and second-generation (Cross-sectionally Augmented Im, Pesaran and Shin Test (CIPS) and Cross-sectionally Augmented Dickey Fuller Test (CADF)) tests strengthens the reliability of these findings, particularly in the presence of CSD. Overall, none of the variables are integrated beyond first order, which satisfies the key requirement for applying the Panel ARDL model.

Table 4. Panel unit root test results.

Variable	LLC		IPS		CIPS		CADF	CADF	Decision
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	
LEFP	-1.742	-10.885***	-1.658	-6.921***	-1.112	-5.432***	-1.987	-3.998***	I(1)
LGDP	-6.554***	-7.812***	-3.104***	-5.923***	-4.712***	-6.204***	-2.994***	-4.552***	I(0)
LAI	-5.231***	-11.205***	-3.011***	-8.104***	-3.542***	-5.001***	-3.662***	-5.204***	I(0)
LBD	-4.987***	-5.002***	-2.998***	-6.203***	-4.511***	-5.442***	-3.004***	-4.223***	I(0)
LSMC	-5.342***	-10.664***	-3.655***	-5.008***	-3.118***	-4.772***	-3.019***	-4.214***	I(0)
LURBA	-0.648	-4.221***	-1.402	-3.224***	-1.221	-3.442***	-1.554	-4.011***	I(1)

The results of the Westerlund panel cointegration test confirm the existence of a long-run equilibrium relationship among the variables. All four test statistics (Gt, Ga, Pt, and Pa) are statistically significant at conventional levels, as indicated by p-values below 0.05. Consequently, the null hypothesis of no cointegration is rejected. These findings imply that EF, economic growth, AI, BD, SMC, and urbanization move together over time in the Nordic region. The presence of cointegration validates the use of the Panel ARDL model, allowing for the estimation of both short-run dynamics and long-run relationships.

Table 5. Westerlund panel cointegration test results.

Statistic	Value	Z-Value	P-Value
Gt	-3.102	-3.102	0.008
Ga	-6.214	1.845	0.017
Pt	-5.113	-1.732	0.028
Pa	-4.689	1.204	0.011

The Panel ARDL results provide important insights into both short-run and long-run dynamics affecting EF in the Nordic region. In the long run, economic growth (LGDP) exerts a positive and statistically significant effect on EF, indicating that higher income levels increase environmental pressure through greater resource consumption and energy demand. Similarly, LSMC shows a strong positive relationship with EF, suggesting that financial market expansion may intensify industrial activities and environmental degradation. LURBA also demonstrates a significant positive impact in both the short and long run. This implies that increasing urban population contributes to ecological stress due to higher infrastructure demand, energy use, and waste generation [18]. The short-run effect is slightly weaker but still meaningful, reflecting immediate environmental pressures associated with rapid urban expansion. In contrast, LAI exhibits a negative and significant effect in the long run, suggesting that technological innovation contributes to improving environmental sustainability. Although the short-run effect is negative but insignificant, the long-run result highlights the potential of AI in enhancing energy efficiency and reducing ecological pressure over time. LBD also shows a negative and significant long-run effect on EF, indicating that financial intermediation may support environmentally friendly investments and sustainable projects [25]. However, its short-run impact remains insignificant, reflecting delayed environmental benefits. The ECT is negative and highly significant, confirming the existence of a stable long-run equilibrium. The coefficient indicates that approximately 57% of short-run deviations are corrected each period, implying a relatively fast adjustment toward equilibrium.

Table 6. Panel ARDL results.

Variable	Long-Run Coef.	Prob.	Short-Run Coef.	Prob.
LGDP	0.112**	0.021	0.148***	0.000
LAI	-0.085**	0.038	-0.049	0.172
LBD	-0.198**	0.029	-0.118	0.141
LSMC	0.256***	0.000	0.072	0.132
LURBA	0.743***	0.000	0.689*	0.081
ECT	-0.571***	0.000	-	-

6 | Conclusion

This study examines the determinants of EF in Nordic economies by focusing on the roles of AI innovation, financial development, economic growth, and urbanization within a panel ARDL framework. The findings reveal that economic growth, SMC, and urbanization significantly increase ecological pressure, indicating that expansion in economic and financial activities continues to challenge environmental sustainability even in advanced economies. In contrast, AI and BD contribute to reducing EF in the long run, highlighting the potential of technological innovation and financial intermediation in supporting sustainable outcomes. The presence of a stable long-run relationship among the variables confirms that environmental sustainability in the Nordic region is shaped by both economic and structural factors. The significant error correction mechanism further suggests that short-run deviations are corrected relatively quickly, reinforcing the robustness of the model.

The empirical findings offer several important policy implications for enhancing environmental sustainability in the Nordic region. First, given the positive impact of economic growth on EF, policymakers should promote a transition toward green growth by integrating renewable energy, resource-efficient production, and low-carbon technologies into economic activities. Emphasis should be placed on decoupling growth from environmental degradation through innovation-driven strategies. Second, the adverse environmental effect of stock market expansion highlights the need to strengthen sustainable finance frameworks. Regulators should encourage green investment practices by promoting environmental, social, and governance standards, green bonds, and climate-related disclosure requirements. This would ensure that capital markets support environmentally responsible projects rather than resource-intensive activities. Third, the beneficial role of AI suggests that governments should invest in eco-friendly digital infrastructure and support research AI in green AI applications. Incentives such as tax benefits and subsidies can accelerate the adoption of AI technologies that improve energy efficiency and environmental monitoring. Fourth, banking sector policies should prioritize green lending by directing financial resources toward sustainable industries and renewable energy projects. Strengthening regulatory guidelines can further align banking operations with environmental objectives. Finally, sustainable urban planning is essential to mitigate the environmental impact of urbanization. Policies promoting smart cities, efficient public transport, and green infrastructure can significantly reduce ecological pressure while maintaining urban growth.

This study suggests that policymakers should further strengthen green innovation, sustainable finance, and smart urban planning to reduce ecological pressure. Encouraging investment in renewable energy, green technologies, and environmentally responsible financial instruments remains essential for long-term sustainability. Future research can extend this analysis by incorporating broader sustainability indicators such as load capacity factor or carbon intensity to provide deeper insights. Additionally, exploring nonlinear relationships, threshold effects, or country-specific dynamics may enrich the understanding of environmental transitions. Expanding the dataset to include emerging economies or applying advanced econometric techniques could also offer more comprehensive and globally relevant findings.

Authors' Contributions

T. T.: writing-original draft, methodology, data curation, conceptualization, software, and visualization, and validation. K. M.: writing-review and editing, formal analysis, and investigation. S. I. T.: writing-review and editing, formal analysis, and investigation. M. O. F.: validation, writing-review and editing, and formal analysis. 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.

Funding

No external funding was received for this research.

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.

References

[1] Fakher, H. A., & Idroes, G. M. (2025). Room for improving the ecological sustainability gap in G20 economies through the lens of load capacity factor: The role of green energy initiatives as moderators. *Innovations in environmental economics*, *1*(1), 1–18. https://doi.org/10.48313/iee.v1i1.33

[2] Raihan, A., Voumik, L. C., Ridwan, M., Ridzuan, A. R., Jaaffar, A. H., & Yusoff, N. Y. M. (2023). From growth to green: Navigating the complexities of economic development, energy sources, health spending, and carbon emissions in Malaysia. *Energy reports*, *10*, 4318–4331. https://doi.org/10.1016/j.egyr.2023.10.084

[3] Ko, J., Leung, C. K., & Ridwan, M. (2026). Freezing economies, melting futures: The impact of sanctions on climate adaptation readiness—panel evidence from 68 targeted developing countries. *Sustainable development*. https://doi.org/10.1002/sd.70674

[4] Fakher, H. A., Abedi, Z., Ahmadian, M., & Shaygani, B. (2018). Comparative examine the impact of financial development (Based on money market and capital market) in the intensity of economic growth effects on the environmental performance. *Environmental researches*, *9*(17), 133–146. (**In Persian**)

[5] Fakher, H. A. (2023). The impact of gross domestic product, financial development, energy consumption on environmental quality: With emphasis on six environmental indicators. *Journal of natural environment*, *76*(2), 345–363. (**In Persian**). https://doi.org/10.22059/jne.2023.346356.2469

[6] Fakher, H. A. (2022). Threshold impact of financial development on the composite environmental quality index with emphasis on the role of research and development: Using multi-criteria decision makin and principal component analysis. *Journal of decisions and operations research*, *6*(Special issue), 1-25. (**In Persian**). https://doi.org/10.22105/dmor.2021.272043.1321

[7] Ahmed, M. E., Sony, R. I., Sifat, A. I., Jalal, M. M., Rahman, A., & Zohora, F. (2025). Investigating the role of education and R&D investment in reducing environmental pollution in China: An ARDL analysis. *Environment, innovation and management*, *1*, 2550025. https://doi.org/10.1142/S3060901125500255

[8] Fakher, H. A., Panahi, M., Emami, K., Peykarjou, K., & Zeraatkish, S. Y. (2021). New insight into development of environmental-economic model based on a composite environmental quality index: An

application of principal components analysis. *Journal of decisions and operations research*, *6*(2), 183-209. (**In Persian**). https://doi.org/10.22105/dmor.2021.276820.1334

[9] Idroes, G. M., Fakher, H. A., Hilal, I. S., & Wiranatakusuma, D. B. (2026). N-shaped or inverted n-shaped EKC? The role of renewable and non-renewable energy in environmental sustainability. *Ekonomikalia journal of economics*, *4*(1), 58–87. https://doi.org/10.60084/eje.v4i1.400

[10] Gharbi, I., Rahman, M. H., Muryani, M., Esquivias, M. A., & Ridwan, M. (2025). Exploring the influence of financial development, renewable energy, and tourism on environmental sustainability in Tunisia. *Discover sustainability*, *6*(1), 127. https://doi.org/10.1007/s43621-025-00896-5%0A%0A

[11] Raihan, A., Bala, S., Akther, A., Ridwan, M., Eleais, M., & Chakma, P. (2024). Advancing environmental sustainability in the G-7: The impact of the digital economy, technological innovation, and financial accessibility using panel ARDL approach. *Journal of economy and technology*. https://doi.org/10.1016/j.ject.2024.06.001

[12] Ridwan, M., Antor, Z. A., Ko, J., Akther, A., Leung, C. K., & Ming, W. K. (2026). Carbon taxes and industrial competitiveness: Evidence from energy-intensive industries in the Nordic region. *Frontiers in sustainability*. https://doi.org/10.3389/frsus.2026.1732459

[13] Fakher, H. A. (2021). The role of environmental sustainability, foreign direct investment and trade openness in economic growth: With emphasis on the causal linkage. *Big data and computing visions*, *1*(2), 57–70. https://doi.org/10.22105/bdcv.2021.142227

[14] Onwe, J. C., Ridzuan, A. R., Uche, E., Ray, S., Ridwan, M., & Razi, U. (2024). Greening Japan: Harnessing energy efficiency and waste reduction for environmental progress. *Sustainable futures*, *8*, 100302. https://doi.org/10.1016/j.sftr.2024.100302

[15] Urbee, A. J., Hasan, M. A., Ridwan, M., & Dewan, M. F. (2025). Adaptation and resilience in the face of climate-induced migration: Exploring coping strategies in the urban economy of barishal metropolitan city. *Environment, innovation and management*, *1*, 2550005. https://doi.org/10.1142/S306090112550005X

[16] Raihan, A., Ridwan, M., & Rahman, M. S. (2024). An exploration of the latest developments, obstacles, and potential future pathways for climate-smart agriculture. *Climate smart agriculture*, *1*(2), 100020. https://doi.org/10.1016/j.csag.2024.100020

[17] Ridwan, M. (2025). Artificial intelligence and green development: The role of financial market efficiency in the United States. *Development and sustainability in economics and finance*, 100099. https://doi.org/10.1016/j.dsef.2025.100099

[18] Chandra Voumik, L., Ridwan, M., Hasanur Rahman, M., & Raihan, A. (2023). An investigation into the primary causes of carbon dioxide releases in Kenya: Does renewable energy matter to reduce carbon emission? *Renewable energy focus*, *47*, 100491. https://doi.org/10.1016/j.ref.2023.100491

[19] Ridwan, M., Urbee, A. J., Voumik, L. C., Das, M. K., Rashid, M., & Esquivias, M. A. (2024). Investigating the environmental Kuznets curve hypothesis with urbanization, industrialization, and service sector for six South Asian countries: Fresh evidence from Driscoll Kraay standard error. *Research in globalization*, *8*, 100223. https://doi.org/10.1016/j.resglo.2024.100223

[20] Tithi, S. I. (2025). Pathways to carbon neutrality in the United States: Evaluating private AI investment, financial development, and macroeconomic forces. *International journal of business and economic studies*, *7*(4), 231–242. https://doi.org/10.54821/uiecd.1831647

[21] Sifat, A. I., Zare, Z., & Ridwan, M. (2025). Forecasting drivers of green economy in the United States: Role of FDI and information technology using machine learning approach. *Environment, innovation and management*, *1*, 2550023. https://doi.org/10.1142/S3060901125500231%22

[22] Singla, B., Dyczek, B., Soto, R. M. H., & Mukthar, K. J. (2021). Whatever is seen is sold: Merchandise mantra. *Webology*, *18*(03), 451–461. https://doi.org/10.14704/WEB/V18SI03/WEB18106 %0A

[23] Raihan, A., Hasan, M. A., Voumik, L. C., Pattak, D. C., Akter, S., & Ridwan, M. (2024). Sustainability in Vietnam: Examining economic growth, energy, innovation, agriculture, and forests' impact on CO_2 emissions. *World development sustainability*, *4*, 100164. https://doi.org/10.1016/j.wds.2024.100164

[24] Pushpa, A., Jaheer Mukthar, K. P., Ramya, U., Asis, E. H. R., & Martinez, W. R. D. (2023). Adoption of fintech: A paradigm shift among millennials as a next normal behaviour. *Fintech and cryptocurrency*, 59–89. https://doi.org/10.1002/9781119905028.ch4

[25] Ridwan, M., Aspy, N. N., Bala, S., Hossain, M. E., Akther, A., Eleais, M., & Esquivias, M. A. (2024). Determinants of environmental sustainability in the United States: Analyzing the role of financial development and stock market capitalization using LCC framework. *Discover sustainability*, *5*(1), 319. https://doi.org/10.1007/s43621-024-00539-1%0A%0A

[26] Ravindran, D., Jaheer Mukthar, K. P., Zarzosa Marquez, E., Pérez Falcón, J., Jamanca Anaya, R., & Silva Gonzales, L. (2023). Impact of digital marketing and IoT tools on MSME's sales performance and business sustainability. In *Technological sustainability and business competitive advantage* (pp. 65–77). Springer. https://doi.org/10.1007/978-3-031-35525-7_5%0A%0A

[27] Tithi, S. I., Faruk, M. O., Rafi, A. H., Ahsan, M. T., Hasan, M., Islam, M. S., & Zani, S. (2025). Artificial intelligence-driven decarbonization in the united states: the roles of energy use, foreign direct investment, and economic growth (1990-2022). *Kristu jayanti journal of management sciences (KJMS)*, 1–22. https://doi.org/10.59176/kjms.v4i2.2573

[28] Farukh, M. O., Tithi, S. I., Rafi, A. H., Hasan, M. M., Islam, M. S., Zani, S., & Ahsan, M. T. (2025). Artificial intelligence, structural transformation, and carbon emissions in the United States: A stirpat--ARDL approach. *Kristu jayanti journal of management sciences (KJMS)*, 23–44. https://doi.org/10.59176/kjms.v4i2.2574

[29] Voumik, L. C., Rahman, M. H., Rahman, M. M., Ridwan, M., Akter, S., & Raihan, A. (2023). Toward a sustainable future: Examining the interconnectedness among foreign direct investment (FDI), urbanization, trade openness, economic growth, and energy usage in Australia. *Regional sustainability*, *4*(4), 405–415. https://doi.org/10.1016/j.regsus.2023.11.003

[30] Nagadeepa, C., Mukthar, K. P. J., Ramirez Asis, E., Nivin Vargas, L., Castillo Picon, J., & Saenz Rodriguez, R. (2023). The "Metaverse Mania" in healthcare education: Students' technology acceptance. *The international conference on global economic revolutions* (pp. 157–174). Springer. https://doi.org/10.1007/978-3-031-50518-8_13%0A%0A

[31] Zani, S., Tithi, S. I., Faruk, M. O., Rafi, A. H., Ahsan, M. T., Hasan, M., & Islam, M. S. (2025). Do finance and digitalization foster environmental sustainability? Evidence from US carbon emissions. *Kristu jayanti journal of management sciences (KJMS)*, 45–66. https://doi.org/10.59176/kjms.v4i2.2575

[32] Raihan, A., Ridwan, M., Rahman, S. M., Sarker, T., Atasoy, F. G., Islam, S., & Akter, R. (2025). Balancing growth and sustainability: The role of women's empowerment, innovation, and green transitions. *Innovation and green development*, *4*(6), 100315. https://doi.org/10.1016/j.igd.2025.100315

[33] Murugesan, T. K., Asis, E. R., KP, J. M., Calderón, J. V., Guerrero, F. J., Picon, J. C., & Diaz, G. P. (2022). Developing and validating constructs: A pragmatic measurement of financial inclusion as a tool for sustainable growth. *Sustainability*, *14*(20), 12955. https://doi.org/10.3390/su142012955

[34] Ko, J., Chen, X., Xin, C., Esquivias, M. A., & Ridwan, M. (2026). Divided by globalization? The impact of globalization on divorce rates across 120 countries. *International journal of sociology*, *56*(2), 79–105. https://doi.org/10.1080/00207659.2026.2632635

[35] Jaheer Mukthar, K. P., Nagadeepa, C., Selvaratnam, D. P., Pushpa, A., & Shukla, N. (2024). Sustainable wardrobe: Recycled clothing towards sustainability and eco-friendliness. *Discover sustainability*, *5*(1), 151. https://doi.org/10.1007/s43621-024-00358-4%0A%0A

[36] Ahmad, S., Raihan, A., & Ridwan, M. (2024). Role of economy, technology, and renewable energy toward carbon neutrality in China. *Journal of economy and technology*, *2*, 138–154. https://doi.org/10.1016/j.ject.2024.04.008

[37] Fakher, H. A. (2020). Analytical insights on the relationship between economic growth and environmental degradation in framework of EKC hypothesis and various environmental indicators. *Innovation management and operational strategies*, *1*(3), 252-268. (**In Persian**). https://doi.org/10.22105/imos.2021.272348.1032

[38] Huerta Soto, R., Ramirez Asis, H., Mukthar, K. P. J., Rurush Asencio, R., Villanueva Calderón, J., & Zarzosa Marquez, E. (2022). Purchase intention based on the brand value of pharmacies in a locality of the peruvian highlands. *International conference on business and technology* (pp. 67–78). Springer. https://doi.org/10.1007/978-3-031-26956-1_7%0A%0A

[39] Ridwan, M., Hassan, M. R., Debnath, A., Akther, A., Khudoykulov, K., Haseeb, M., & Hossain, M. E. (2025). AI innovation, globalization, and trade freedom: Drivers of environmental sustainability in BRICS-T nations. *Environment, development and sustainability*, 1–25. https://doi.org/10.1007/s10668-025-07090-7%0A%0A

[40] Rafi, A. H., Tithi, S. I., Faruk, M. O., Ahsan, M. T., Hasan, M., Islam, M. S., & Zani, S. (2025). Digital finance and ecological sustainability: Revisiting the load capacity curve in the United States. *Kristu jayanti journal of management sciences (KJMS)*, 67–86. https://doi.org/10.59176/kjms.v4i2.2576

[41] Leelavathi, R., Philip, B., Madhusudhanan, R., Sony, N., & Mukthar, K. P. J. (2024). Ai-driven customer relationship management (CRM): A review of implementation strategies. *Anticipating future business trends: Navigating artificial intelligence innovations: Volume 2*, 283–295. https://doi.org/10.1007/978-3-031-63402-4_22%0A%0A

[42] Tithi, S. I. (2025). Machine learning-driven predictive models for urban sustainability in the context of digital transformation. *Innovations in environmental economics*, *1*(2), 96–108. https://doi.org/10.48313/iee.v1i2.42

[43] Shantha Kumari, K. G., Jaheer Mukthar, K. P., & El Rahhani, G. N. (2024). Green finance in India: Driving sustainable development and economic growth. In *Business development via ai and digitalization: Volume 2* (pp. 283–293). Springer. https://doi.org/10.1007/978-3-031-62106-2_23%0A%0A

[44] Mukthar, K. P. J., Chauhan, N., Al Absy, M. S. M., Kumar, R. N., Gupta, N. R., & Gokilavani, S. (2025). Research dynamics in AI and fintech: A bibliometric investigation using R. *Discover internet of things*, *5*(1), 19. https://doi.org/10.1007/s43926-025-00111-x%0A%0A

[45] Biju, H., Mukthar, K. P. J., Dhia, A., Selvaratnam, D. P., Singh, S. K., & Singh, J. K. (2024). A bibliometric analysis of financial technology: Unveiling the landscape of a rapidly evolving field. *Discover sustainability*, *5*(1), 72. https://doi.org/10.1007/s43621-024-00256-9%0A%0A

[46] Adlinda, S., Brindha, G., Reshma, M., Jaheer Mukthar, K. P., Ko, J., Ridwan, M., & Ming, W. (2026). The mediating role of conscious consumerism in shaping sustainable consumption intentions: Evidence from Coimbatore district, India. *Frontiers in sustainability*, *7*, 1755124. https://doi.org/10.3389/frsus.2026.1755124

[47] Pattak, D. C., Tahrim, F., Salehi, M., Voumik, L. C., Akter, S., Ridwan, M., & Zimon, G. (2023). The driving factors of Italy's CO2 emissions based on the STIRPAT model: ARDL, FMOLS, DOLS, and CCR approaches. *Energies*, *16*(15), 5845. https://doi.org/10.3390/en16155845

[48] Tithi, S. I. (2026). Towards sustainable development goals: An ARDL analysis of energy efficiency, finance, and technology in mitigating CO_2 emissions in the United States. *Systemic analytics*, *4*(1), 13–26. https://doi.org/10.31181/sa41202667

[49] Raihan, A., Joarder, M. S. A., Rahman, S. M., Bari, A. B. M. M., Ridwan, M., & Sarker, T. (2025). Renewable energy resources for green development in Bangladesh: Perspectives, challenges, and opportunities. *Innovation and green development*, *4*(5), 100298. https://doi.org/10.1016/j.igd.2025.100298

[50] Jubayed, A. Al. (2025). Machine learning-driven insights into sustainability trends in the United States: Examining financial and economic influences. *Environment, innovation and management*, *1*, 2550015. https://doi.org/10.1142/S3060901125500152

[51] Ridwan, M., Akther, A., Tamim, M. A., Ridzuan, A. R., Esquivias, M. A., & Wibowo, W. (2024). Environmental health in BIMSTEC: the roles of forestry, urbanization, and financial access using LCC theory, DKSE, and quantile regression. *Discover sustainability*, *5*(1), 429. https://doi.org/10.1007/s43621-024-00679-4%0A%0A

[52] Polcyn, J., Voumik, L. C., Ridwan, M., Ray, S., & Vovk, V. (2023). Evaluating the influences of health expenditure, energy consumption, and environmental pollution on life expectancy in Asia. *International journal of environmental research and public health*, *20*(5), 4000. https://doi.org/10.3390/ijerph20054000

[53] Tithi, S. I. (2025). Decarbonizing the US economy through artificial intelligence and information technology: An empirical ARDL analysis. *Information sciences and technological innovations*, *2*(2), 108–120. https://doi.org/10.48314/isti.v2i2.45

[54] Voumik, L. C., & Ridwan, M. (2023). Impact of FDI, industrialization, and education on the environment in Argentina: ARDL approach. *Heliyon*, *9*(1), e12872. https://doi.org/10.1016/j.heliyon.2023.e12872