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Nexus among Ecological Footprint, Green Finance and Renewable Energy Consumption: A Global Perspective

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Abstract

Environmental sustainability has become a pressing concern amid accelerating industrialization and economic growth, which have collectively intensified ecological degradation. This study investigates the interconnected roles of green finance and renewable energy consumption in influencing ecological footprints across developed and developing countries from 1995 to 2021. Drawing on ecological modernization theory and sustainable development theory, the analysis employs panel least squares and generalized method of moments methods to examine data from fifty-four countries, using ecological footprint as the dependent variable, while renewable energy consumption and green finance are key explanatory factors. Empirical findings indicate that non-renewable energy consumption significantly increases ecological footprints in all regions, whereas renewable energy reduces ecological impact most notably in developed countries.

Green finance contributes to environmental improvement in advanced economies but exhibits a positive correlation with ecological footprint in developing countries, likely due to the transitional nature of green investments. Population density consistently shows a mitigating effect on ecological degradation. These results underscore the importance of tailored green finance policies, technology transfer, and renewable energy expansion, particularly in developing nations, to support global sustainability targets.

Keywords	Ecological Footprint, Green Finance, Renewable Energy Consumption, Sustainability

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INTRODUCTION

Industrialization, urbanization, and sustained economic expansion have intensified pressure on ecosystems, making it essential to clarify how ecological footprint, green finance, and renewable energy consumption interact to support global sustainable development (Zhang et al., 2019; Al-Masri & Ibrahim, 2025; Audi et al., 2025). Over the past three decades, many nations have recorded remarkable increases in output, now contributing a substantial share of global production (World Bank, 2023). Even so, the combined real gross domestic product of the world's major economies reached only twenty-five-point-three-six trillion United States dollars in twenty-twenty-three (at two-thousand-ten prices), a figure that illustrates persistent disparities across regions (International Monetary Fund, 2023). Ecological footprint quantifies the biologically productive land and water required to supply society with food, energy, and materials while absorbing the resulting waste. It therefore exposes the gap between resource demand and the planet's regenerative capacity, incorporating variables such as carbon-dioxide emissions, nutrient loading, terrestrial acidification, and ecotoxicity (Solarin et al., 2019; Raihan, 2024; Geddes et al., 2020; Bashir et al., 2022; Irfan & Sohail, 2021; Khalid & Abdul, 2025). Current data show that humanity consumes natural capital at a rate equivalent to one-point-seven-five Earths, meaning that more than eighty percent of the global population lives in countries that demand ecological services beyond domestic biocapacity.

Green finance directs capital toward projects that advance environmental objectives, including renewable-energy deployment, clean technologies, sustainable agriculture, and pollution control (Chenet et al., 2019; Alvi & Mudassar, 2025; Audi et al., 2025). By reallocating funds from carbon-intensive to low-carbon activities, the financial sector becomes a catalyst for decarbonization and long-term economic prosperity. Complementing this shift, renewable-energy consumption—drawn from solar, wind, hydropower, geothermal, and bio-energy sources, stimulates output, enhances energy security, and alleviates climate pressures (Rahman and Velayutham, 2020; Jamel & Zhang, 2024). Empirical evidence confirms that renewable technologies both spur growth and moderate ecological degradation (Farhani and Shahbaz, 2014; Wang & Li, 2024; Sulehri et al., 2024). Large economies with significant populations and carbon profiles therefore play a pivotal role in global climate mitigation. Insight into their patterns of green finance, renewable-energy uptake, and ecological footprints can inform effective policies at home and abroad (Danish & Wang, 2019; Al-Masri & Wimanda, 2024). Existing research highlights the environmental strain associated with rapid industrialization in these nations and documents ecological-footprint dynamics across multiple contexts (Ali & Audi, 2016; Aydin, 2019; Bello et al., 2018; Destek & Sarkodie, 2019; Ozcan et & Ozturk, 2019; Sarkodie & Strezov, 2018; Ulucak & Bilgili, 2018; Ramanust, 2023). Recent capacity additions underscore the transformational potential of renewables, China and the United States together have accounted for roughly one-half of new renewable installations worldwide, while India's solar-power surge illustrates both progress and the persistent challenge of coal dependence (International Renewable Energy Agency, 2021).

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Building on this background, the present study investigates the intricate relationships among ecological footprint, green-finance flows, and renewable-energy consumption in leading and emerging economies. It evaluates how green finance can accelerate the renewable-energy transition and mitigate environmental pressures associated with industrial growth and synthesizes cross-country evidence to chart prevailing trends, challenges, and opportunities for sustainable practice (Ali et al., 2021; Bashir et al., 2022; Singh & Kumar, 2023). Ecological-footprint expansion has direct human consequences: degraded air quality, diminished water supplies, food insecurity, and elevated public-health risks.

The World Health Organization attributes roughly thirteen million deaths each year to environmental factors, with air pollution alone responsible for about seven million fatalities (WHO, 2023). Continued reliance on fossil fuels in both advanced and developing economies widens the gulf between economic advancement and ecological resilience (Global Footprint Network, 2022). In response, green finance has emerged as a strategic instrument for channeling investment toward renewable technologies that reduce carbon emissions and environmental degradation (Sachs, 2021; Li et al., 2023; Saluy & Nuryanto, 2023). Nevertheless, the literature still lacks comprehensive analysis of how green-finance mechanisms and renewable-energy deployment jointly influence ecological footprints. By examining their combined impact, this study addresses that gap and offers evidence-based guidance for policy makers seeking to balance economic growth with environmental stewardship. Ultimately, the findings aim to advance global sustainable-development objectives by demonstrating that prosperity need not compromise planetary health.

LITERATURE REVIEW

A growing body of research documents how ecological footprint, green finance and renewable energy consumption interact within specific regions, yet a comprehensive global comparison remains unavailable. The earliest contributions to the debate emphasise how globalisation alters the relationship between markets, technology and regulation. Garrett (2000) shows that falling transport and information costs deepen economic inter-dependence, but warns that domestic policy choices ultimately decide whether integration accelerates or restrains environmental decline. Sadorsky (2009) demonstrates that rising personal income in emerging markets stimulates demand for renewable energy, although higher electricity prices temper that effect; together, these findings underline the importance of income growth and pricing signals in steering energy choices. Ruževičius (2010) compares ecological deficits and reserves across countries, concluding that consumption in high-income economies already exceeds Earth’s regenerative capacity and that ecological footprint alone cannot capture social and economic dimensions of sustainability.

Apergis and Payne (2012) uncover two-way causality between renewable and non-renewable energy use and economic output in eighty countries, indicating that decarbonisation policies must consider feedback effects on growth. Farhani and Shahbaz (2014) confirm that both renewable and fossil-fuel electricity raise carbon dioxide emissions in the Middle East and North Africa, while Shafiei and Salim (2014) find that, after a threshold, urbanisation in the Organisation for Economic Co-operation

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and Development reduces environmental damage, supporting the Environmental Kuznets Curve hypothesis. Campiglio (2016) argues that monetary and financial policy instruments, such as differentiated capital requirements for low-carbon lending, could correct credit-market failures that hamper green investment. Oertel et al. (2016) remind scholars that soils themselves are major greenhouse-gas sources, stressing the need for better land-use data, while Heryadi and Hartono (2016) show that both energy efficiency and renewable power curb emissions in the Group of Twenty.

Destek and Sarkodie (2018) detect an inverted-U Environmental Kuznets Curve in newly industrialised states but note that financial development enlarges ecological footprints. Liu and Kim (2018) report that foreign direct investment in Belt and Road economies follows a "pollution-haven" pattern unless environmental standards tighten. Cao et al. (2019) reveal that volatile international oil prices discourage renewable-energy investment among Chinese firms, especially those relying on government support. Danish & Wang, (2019) observe that renewable power and urbanisation reduce ecological footprints in Brazil, Russia, India, China and South Africa, whereas initial income growth intensifies pressure—a result echoed by Iwińska et al. (2019), who show that the quality of democracy shapes environmental outcomes through governance effectiveness and corruption control. Sachs et al. (2019) highlight green bonds and financial-technology platforms as critical channels for mobilising capital towards low-carbon energy.

Dutta et al. (2020) find that volatility in the broader energy sector depresses returns on clean-energy exchange-traded funds, especially in high-risk regimes, urging investors to hedge against sectoral shocks. Geddes et al. (2020) show that partisan conflict in Australia hampers the creation of green investment banks compared with consensus-driven legislation in the United Kingdom. Lee (2020) notes that China's rapid green-bond market growth is slowed by inconsistent definitions and limited transparency, calling for harmonised standards. Alam and Murad (2020) demonstrate that long-run renewable-energy uptake in the Organisation for Economic Co-operation and Development depends on sustained economic growth, open trade and continued technological innovation.

Sharma et al. (2021) show that energy use and financial-sector expansion raise carbon emissions in South and South-East Asia, but that income growth eventually reverses the trend, again supporting the Environmental Kuznets Curve. A parallel study by Sharma et al. (2021) finds that financial development magnifies ecological, carbon and land footprints, particularly when combined with heavy energy use. Ibrahim and Ajide (2021) establish that eco-innovation dampens the harmful effect of non-renewable energy and imports on carbon emissions in the Group of Twenty. Nedopil et al. (2021) trace how diverse governance structures have shaped eighty-four green-finance standards since 1998, showing no single template fits all contexts. Liu et al. (2021) conclude that green finance, financial technology and inclusive finance jointly enhance energy efficiency in emerging economies. Gilchrist et al. (2021) caution, however, that the full stakeholder benefits of corporate "greenness" remain difficult to measure.

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Yin et al. (2022) identify an Environmental Kuznets Curve turning point at thirty-eight thousand United States dollars per capita for the Group of Twenty and show that internet access, renewable energy and trade in services lower carbon emissions, especially in advanced economies. Raheem et al. (2022) forecast rising non-renewable energy consumption in the Group of Twenty, with natural gas displacing coal. Sadiq & Wen, (2022) find that nuclear energy reduces ecological footprints in the ten worst-performing countries, while globalisation and growth worsen them. Udemba (2022) shows that economic activity in Nigeria drives ecological pressure, whereas population growth has a mitigating effect. Sampene et al. (2022) demonstrate that renewable energy and green finance lessen ecological footprints in South Asia, but natural-resource rents and agricultural expansion have the opposite effect. Ahmed et al. (2022) find that environmental regulation curbs ecological footprints across the Group of Seven, while democratic processes may raise them unless complemented by stringent rules. Ajide and Mesagan (2022) show that capital investment cuts pollution when aligned with renewable power, but raises it when linked to fossil energy. Islami et al. (2022) reach similar conclusions for carbon emissions in the Group of Twenty.

Tran (2023) finds that green trade, renewable power and green finance jointly reduce greenhouse-gas emissions in the Association of South-East Asian Nations, whereas rapid industrialisation offsets part of the gain. Jiang and Jiang (2023) show that China's Green Credit Guidelines raise productivity but reduce labour demand in heavily polluting firms, signalling a trade-off between environmental targets and employment. Dong et al. (2023) report that geopolitical risk shocks spur green-finance development in Brazil, Russia, India, China and South Africa, particularly when renewable-energy investment rises. Arshad et al. (2023) warn that foreign investment and digitalisation increase carbon emissions in South Asia unless counterbalanced by renewable energy. Ayad et al. (2023) establish that economic-policy uncertainty elevates carbon emissions across income levels, implying that stable regulatory frameworks are critical for mitigation. Abhilash et al. (2023) identify illiquidity, weak disclosure and limited investor awareness as barriers to scaling green finance in India.

The most recent literature further refines the links among green finance, innovation and environmental quality. Karaham-Dursun (2024) replace conventional pollution indicators with ecological and human-capital metrics, confirming the Environmental Kuznets Curve in Turkey and showing that human capital lowers ecological footprints. Yavuz et al. (2024) document that carbon dioxide emissions and ecological footprints raise health expenditures in Turkey, whereas greater biocapacity lowers them, underscoring the social costs of environmental degradation. Abbas et al. (2024) synthesise fifty studies and conclude that renewable resources reduce environmental damage while fossil resources intensify it, calling for place-specific policies. Idroes et al. (2024) find that renewable energy consistently suppresses both carbon emissions and ecological footprints in Indonesia, and that oil is the most damaging non-renewable fuel. Leite and Fontgalland (2024) show that Brazil's vast biocapacity is eroded by uneven consumption patterns, especially in large urban centres, and recommend locally tailored interventions. Morshed et al. (2024) project that unchecked urban expansion could exhaust the biocapacity of Khulna City by 2035,

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highlighting the urgency of sustainable urban planning. Wang et al. (2024) reveal that trade liberalisation alters the Environmental Kuznets Curve through double-threshold effects, benefiting high-income economies but harming lower-income ones. Dam et al. (2024) confirm that technological innovation and renewable energy curb ecological footprints in the Emerging Seven, while natural-resource rents and income expansion have the reverse impact. Hacıimamoğlu and Cengiz (2024) find similar results for the Association of Southeast Asian Nations Five, advocating reinvestment of resource rents in clean energy.

Imran et al. (2024) note that ecological footprints and carbon emissions raise financial-sector stability in South Asia, but renewable energy mitigates that effect, suggesting a complex finance–environment nexus. Mohamed et al. (2024) reconfirm the Environmental Kuznets Curve in China and show that renewable electricity reduces emissions, albeit with ambiguous effects on ecological footprints. Raihan (2024) discover that public–private partnerships in energy enlarge ecological footprints in Brazil unless offset by renewable consumption and financial development. Öncel et al. (2024) demonstrate that shocks to non-renewable energy from Russia worsen ecological footprints in importing states, advocating a strategic pivot towards domestic renewable sources. Shah et al. (2024) show that renewable energy raises energy efficiency in the Group of Twenty, even though overall productivity gains hinge on technological progress. Espinosa and Koh (2024) forecast that only four Group of Twenty members will maintain a positive ecological balance by 2050, calling for concerted reforms. Alghamdi et al. (2024) report that both renewable and nuclear energy lower carbon dioxide emissions in the Group of Twenty, while non-renewable consumption raises them. Aslam et al. (2024) and Chen et al. (2024) independently confirm that green finance lowers ecological footprints and carbon dioxide emissions in East Asia, the Pacific and Belt and Road economies. Li et al. (2024) reach the same conclusion for China, stressing the complementary roles of renewable power and technological innovation. Sharif et al. (2024) find that green technology and renewable power reduce ecological footprints in the ten most environmentally stressed countries but that globalisation intensifies pressure, whereas Zhang and Yasin (2024) show that green innovation only achieves its full potential when institutional quality is high. Wang et al. (2024) identify climate technology and renewable energy as the most effective levers for reducing ecological footprints in heavily polluted economies, though financial inclusion yields mixed outcomes. Sun & Rasool, (2024) use quantile-on-quantile methods to reveal that green finance lowers ecological footprints across most European economies, but country-specific policies determine the strength and even the direction of the effect. Uche et al. (2024) illustrate the heterogeneous impacts of green taxation and innovation on carbon emissions in South Africa, encouraging regularly updated policy mixes. Bai and Lin (2024) show that Chinese enterprises with moderate risk appetites benefit most from green-finance incentives to innovate. Finally, Dam et al. (2024) and Hacıimamoğlu and Cengiz (2024) converge in recommending that emerging economies channel natural-resource rents into technological innovation and renewable-energy deployment.

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Recent contributions illustrate the point, Aslam et al. (2024) and Chen et al. (2024) examine green finance in East Asia and in Belt and Road Initiative economies, respectively, while Dam et al. (2024) and Hacıimamoğlu and Cengiz (2024) find that renewable energy curbs environmental degradation in the Emerging Seven and in five Association of Southeast Asian Nations member states. These geographically targeted studies highlight valuable regional insights but leave unanswered questions about how policy frameworks, technological progress and financial instruments differ across continents. Most studies also rely on cross-sectional or short-panel designs, providing only snapshots of the link between green financial flows, renewable-energy deployment and ecological pressure. The absence of long-horizon, multi-country panels limits our understanding of whether sustained green-finance growth or cumulative renewable-energy adoption moderates ecological footprints over time. Raihan (2024) do incorporate public–private partnership investments in renewable energy, yet comparable evidence on the joint influence of green finance and renewable energy at the worldwide level is still scarce. Another gap concerns heterogeneity in green-finance implementation across countries. Sun & Rasool, (2024) report mixed results within Europe, underscoring the need for contextualised analysis, but no study has systematically explored how differences in green-finance architecture shape ecological outcomes on a global scale. Addressing these omissions calls for longitudinal, cross-country models that capture bilateral and sector-level interactions among ecological footprint, green finance and renewable energy. Such work would equip researchers and policymakers with clearer guidance for designing coordinated strategies to achieve environmentally sustainable development worldwide.

THEORETICAL MODEL

Environmental stability is an essential pre-condition for sustained economic growth; without policies that restrain ecological pressure, prosperity cannot last. Ecological Modernization Theory, first articulated by Joseph Huber and Martin Janicki in the early 1980s and later refined by Mol and Spaargaren (2000), offers a framework in which growth and environmental protection reinforce, rather than oppose, one another. The theory posits that technological innovation, green finance and institutional reform can realign production so that economic expansion proceeds without accelerating ecological damage. Green finance channels capital toward low-carbon projects, thereby lowering the ecological footprint by underwriting renewable-energy systems that deliver both financial and environmental returns (Mol, 1995). Renewable-energy deployment itself is central to Ecological Modernization Theory: replacing fossil fuels with wind, solar and geothermal resources reduces carbon emissions while creating new industries and jobs, especially in late-industrializing economies (York & Rosa, 2003). Yet technology and capital alone do not guarantee success. Robust governance and clear regulation determine whether green-finance flows and renewable-energy schemes achieve genuine environmental gains; aligning national policy with sustainability objectives improves energy efficiency, spurs innovation, and eases pressure on natural resources (Jänicke, 2008; Wang & Manopimoke, 2023). In short, Ecological Modernization Theory links economic development and environmental quality by showing how societies can deploy new technologies, reform industries and

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enact supportive policy to reduce risk while advancing material well-being (Sonnenfeld & Mol, 2002; Kosyak & Popov, 2020).

To broaden this perspective, the present study also draws on Sustainable Development Theory, rooted in the Brundtland Commission's definition of development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainable Development Theory stresses prudent resource use, targeted green-finance investment and continuous technological progress. Green finance supplies the capital required to diffuse large-scale renewable-energy projects, cushioning economic vulnerability and accelerating the low-carbon transition in both industrialized and emerging economies (UNEP, 2021). Renewable-energy adoption simultaneously mitigates climate change, diversifies the energy base, creates employment, and enhances energy security (IRENA, 2020). Sustainable-Development-Theory likewise emphasizes strong institutions and coherent governance: when national strategies align with long-term sustainability goals, innovation accelerates, resource efficiency deepens and economic returns improve (Sachs, 2015).

Guided by these complementary theories, the mathematical model can be written as:

$$EFP_{it}=F\ (GF_{it},\ REC_{it},\ X_{it}) \qquad (1)$$

Equation (1) where EFP represents the ecological footprint (measured in global hectares per person), which serves as the dependent variable. It is influenced by REC (renewable energy consumption as a percentage of total final energy consumption) and Green finance, measured using the proxy Expenditure on environment protection, GDP% both of which are the independent variables.

The control variables, represented as NREC (nonrenewable energy consumption) measured by Electric power consumption (kwh per capita) and PD (population density measured as people per square kilometer), which help account for variations caused by economic and demographic factors. The subscripts i and t denote developed and developing countries and the time period (1995–2021), respectively. This model provides a framework to analyze how green finance and renewable energy consumption affect the ecological footprint while controlling for external factors like economic growth and population pressures, offering insights into sustainable development from a global perspective. The econometric model used for the empirical analysis is shown below.

$$EFP_{it} = \beta0 + \beta_1 GF_{it} + \beta_2 REC_{it} + \beta_3 NREC_{it} + \beta_4 PD_{it} + \epsilon_{it}. \qquad (2)$$

Equation (2) presents an econometric model of the current study for achieving the main objectives. Ecological Footprint is the dependent variable. Green Finance and Renewable Energy Consumption are treated as an in independent variables. Non-renewable Energy Consumption and Population Density are the control variables used in this study to achieve the main objectives of the study. The β coefficient represents the estimated effects of each variable on ecological footprint. ϵ_{it} is the error term, which represents the unexplained variability in the dependent variable.

Descriptive statistics, correlation matrix, panel least squares, and generalized method of moments have been used for the empirical analysis for twenty-seven developed and twenty-seven developing from 1995 to 2021. The data of selected variables have been taken from the World Bank.

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RESULTS AND DISCUSSIONS

This part of the study is comprised empirical results and discussions. Descriptive statistics offer essential insights into datasets by summarizing measures of central tendency, variability, and distribution, crucial for identifying trends and characteristics within the data. Table 1 presents the descriptive statistics separately for developed countries, developing countries, and the combined whole sample. The dependent variable is ecological footprint, while green finance, renewable energy consumption, non-renewable energy consumption, and population density serve as independent and control variables. In developed countries, the average ecological footprint is 6.2677, with a standard deviation of 2.1071, illustrating significant dispersion around this average. Ecological footprint values range widely from a minimum of 3.1352 to a maximum of 17.2828, highlighting pronounced disparities among these nations. The mean value for green finance is 0.6669, demonstrating moderate variability, as indicated by the standard deviation of 0.3376, and ranges between a minimum of -0.2600 and a maximum of 1.7400. Renewable energy consumption shows a substantial mean value of 17.1551 with a considerable standard deviation of 14.6228, reflecting substantial variation from the lowest observed value of 0.3000 to the highest value of 61.4000. Non-renewable energy consumption has an average of 8.9032 and exhibits moderate variability (standard deviation 0.5156), ranging from 7.5973 to 10.1500. Population density displays a mean value of 4.5388 and a standard deviation of 1.4574, varying from 1.1843 to 8.9829. Additionally, skewness and kurtosis statistics indicate non-normal distributions across these variables, confirmed further by significant Jarque-Bera tests (probability value equals 0.0000). In contrast, the average ecological footprint in developing countries is considerably lower at 3.045, with a standard deviation of 2.030, indicating substantial variability from a minimum of 0.594 to a maximum of 10.693. Green finance has an average value of 0.478, with a standard deviation of 0.293, ranging from 0 to 1.78. This demonstrates uneven commitments toward green finance among developing countries, with some countries showing significant efforts and others minimal or none. Renewable energy consumption reveals an average of 28.067 with significant variability (standard deviation 27.721), ranging widely from 0 to 95.5. This wide variation highlights the substantial differences in renewable energy adoption among these nations. Non-renewable energy consumption presents an average of 7.183 with a moderate standard deviation of 1.332, ranging between 3.801 and 9.789, suggesting noticeable variations in energy usage patterns. Population density averages 4.189 with a standard deviation of 1.1004, varying from 0.409 to 5.719. Skewness, kurtosis, and significant Jarque-Bera tests (probability value equals 0.0000) collectively confirm non-normal distributions within these variables. Considering the whole sample, the ecological footprint exhibits an average value of 4.6569 and a standard deviation of 2.6220, capturing the broadest range from 0.5942 to 17.2828. Green finance averages 0.5725 with a moderate standard deviation of 0.3300, ranging from -0.2600 to 1.7800. Renewable energy consumption shows moderate variability with a mean value of 4.3639 and a standard deviation of 1.3026, indicating moderate but significant differences among countries.

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TABLE 1: DESCRIPTIVE STATISTICS OUTCOMES

DEVELOPED COUNTRIES

Variable	EFP	LNREC	GF	LPD	REC
Mean	6.267	8.903	0.666	4.538	17.155
Medium	5.799	8.841	0.630	4.630	13.500
Maximum	17.282	10.149	1.740	8.982	61.400
Minimum	3.135	7.597	-0.260	1.184	0.3000
Std. Dev.	2.107	0.515	0.337	1.457	14.622
Skewness	2.135	0.300	0.478	0.442	1.120
Kurtosis	8.944	2.849	3.999	4.200	3.738
Jarque-Bera	1627.423	11.673	58.158	67.522	169.185
Sum	4569.192	6490.431	486.2086	3308.796	12506.10
Sum Sq. Dev.	3232.350	193.5573	82.95244	1546.179	155665.6
Observation	729	729	729	729	729
DEVELOPING COUNTRIES					
Mean	3.045968	7.183724	0.478113	28.06763	4.189050
Median	2.355598	7.478394	0.430526	19.80000	4.541605
Maximum	10.69358	9.789359	1.780000	95.50000	5.719452
Minimum	0.594229	3.801501	0.000000	0.000000	0.409410
Std. Dev.	2.030288	1.332004	0.293551	27.72143	1.100443
Skewness	1.171870	-0.518629	0.527824	1.085045	-1.624661
Kurtosis	4.014858	2.524045	3.317215	2.996874	5.601066
Jarque-Bera	198.1377	39.56150	36.90612	143.0450	526.2056
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	2220.511	5236.935	348.5444	20461.30	3053.818
Sum Sq. Dev.	3000.866	1291.643	62.73351	559451.7	881.5894
Observations	729	729	729	729	729
WHOLE SAMPLE					
Mean	4.656860	8.045329	0.572533	22.61139	4.363933
Medium	4.705173	8.444973	0.570000	16.40000	4.592642
Maximum	17.28278	10.14998	1.780000	95.50000	8.982923
Minimum	0.594229	3.801501	-0.260000	0.000000	0.409410
Std. Dev.	2.621997	1.324810	0.330018	22.81679	1.302645
Skewness	0.867946	-1.089734	0.550812	1.501352	-0.071679
Kurtosis	4.829320	3.669766	3.760968	4.691436	5.245473
Jarque-Bera	386.3539	315.6024	108.9032	721.5390	307.5591
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	6789.702	11722.05	834.7530	32967.40	6362.614
Sum Sq. Dev.	10016.69	2555.457	158.6842	758522.8	2472.360
Observation	1458	1457	1458	1458	1458

Non-renewable energy consumption averages 8.0453 with a standard deviation of 1.3248, highlighting consistent yet distinct variability across the dataset, ranging from 3.8015 to 10.1500. Population density has a high mean value of 22.6114, with a significant

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Annual Methodological Archive Research Review

standard deviation of 22.8168, ranging between 0 and 95.5, signifying substantial demographic disparities. Skewness, kurtosis, and Jarque-Bera test results consistently indicate deviations from normal distributions for all variables (probability value equals 0.0000). Comparatively, developed countries exhibit a higher ecological footprint yet display more stable and consistent patterns in non-renewable energy consumption. In contrast, developing countries demonstrate lower ecological footprints but greater variability in renewable energy adoption and green finance commitment. The whole sample encapsulates these contrasts, reflecting substantial disparities in ecological and energy-related variables, thus establishing a solid foundation for subsequent analytical modeling and hypothesis testing.

The correlation matrix results presented in table 2 illustrate critical insights into relationships among ecological footprint, green finance, renewable energy consumption, non-renewable energy consumption, and population density for developed countries, developing countries, and the entire sample. For developed countries, ecological footprint shows a statistically significant positive relationship with non-renewable energy consumption (correlation coefficient of 0.4972), indicating that greater use of non-renewable energy sources intensifies environmental degradation. Conversely, green finance exhibits a weak negative and statistically insignificant relationship with ecological footprint (coefficient of -0.0585), suggesting minimal direct environmental impact in developed nations from green finance initiatives. Renewable energy consumption is negatively and significantly correlated with ecological footprint (-0.1466), underscoring the role renewable energy plays in reducing environmental pressure. Population density shows a significant negative correlation (-0.3049) with ecological footprint, implying efficient resource utilization in densely populated developed areas. Additionally, the positive correlation (0.2896) between renewable and non-renewable energy consumption highlights their simultaneous use. However, renewable energy consumption and population density are negatively correlated (-0.5577), indicating that higher population density might encourage renewable energy adoption. Overall, correlations among explanatory variables remain moderate, indicating that multicollinearity is not problematic. In developing countries, the ecological footprint also shows a significant positive correlation with non-renewable energy consumption (0.5852), reinforcing that higher dependence on non-renewable energy intensifies ecological impacts. Unlike developed countries, green finance here has a slightly positive yet negligible correlation with ecological footprint (0.1075), suggesting limited effectiveness of green finance in mitigating environmental damage in developing countries. Renewable energy consumption demonstrates a robust negative correlation (-0.4062) with ecological footprint, emphasizing the substantial environmental benefits from renewable energy investments. Population density again negatively correlates (-0.2179) with ecological footprint, indicating denser populations effectively use resources, thereby reducing environmental pressure. Non-renewable energy consumption negatively correlates with renewable energy consumption (-0.5989), suggesting competition between these energy types. Green finance shows negligible correlation (0.0020) with renewable energy consumption, while population density and renewable energy consumption display a modest positive correlation (0.1299), highlighting a minor potential for renewable

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Publisher Name : COLLABORATIVE EDUCATIONAL LEARNING INSTITUTE
Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review
VOL-3, ISSUE-3, 2025

adoption in densely populated areas. As with developed nations, multicollinearity remains within acceptable limits. Analyzing the entire sample reveals the strongest positive relationship between ecological footprint and non-renewable energy consumption (0.7034), clearly highlighting the severe environmental consequences linked with non-renewable energy reliance. Green finance maintains a positive but weak correlation (0.1893) with ecological footprint, reflecting limited environmental impact from existing green finance initiatives. Renewable energy consumption is negatively correlated (-0.1262) with ecological footprint, though weaker compared to developing countries, suggesting varying effectiveness of renewable strategies across nations.

TABLE 2: CORRELATION MATRIX

Variable	EFP	NREC	GF	PD	REC
DEVELOPED COUNTRIES					
EFP	1.0000				
NREC	0.4972***	1.0000			
GF	-0.0585	-0.0874	1.0000		
PD	-0.3049***	-0.3648***	0.0512	1.0000	
REC	-0.1466***	0.2896***	-0.164***	-0.5577***	1.0000
DEVELOPING COUNTRIES					
EFP	1.0000				
NREC	0.5852***	1.0000			
GF	0.1075**	0.0874*	1.0000		
REC	-0.4062***	-0.5989***	0.0020	1.0000	
PD	-0.2179***	0.0073	0.0518	0.1299	1.0000
WHOLE SAMPLE					
EFP	1.0000				
NREC	0.7034***	1.0000			
GF	0.1893***	0.2077***	1.0000		
PD	-0.3756***	-0.4840***	-0.1213***	1.0000	
REC	-0.1262***	0.0104	0.0872***	-0.1652***	1.0000

Population density significantly negatively correlates (-0.3756) with ecological footprint, supporting the idea that dense populations facilitate resource efficiency and sustainability. The positive correlation (0.2077) between non-renewable energy consumption and green finance suggests transitional phases where traditional and green energy coexist. Population density negatively correlates with both non-renewable energy consumption (-0.4840) and renewable energy consumption (-0.1652), highlighting complexities in adopting renewable energy solutions in densely populated areas due to logistical constraints. Overall, correlations are moderate and acceptable, confirming that multicollinearity does not adversely affect subsequent regression analyses. Comparatively, the strongest ecological footprint and non-renewable energy consumption relationship is observed in the whole sample, followed by developing and then developed countries. Green finance shows limited effectiveness across all groups, slightly positive in developing countries and negligible or negative in developed nations. Renewable energy consistently mitigates ecological footprints, most notably in developing countries. Population density consistently promotes resource efficiency, with the strongest effects

ISSN (E) 3007-3197
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Publisher Name : COLLABORATIVE EDUCATIONAL LEARNING INSTITUTE
Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review

VOL-3, ISSUE-3, 2025

observed in the whole sample, emphasizing its critical role in achieving environmental sustainability.

The results of the panel simple regression analysis in Table 3 highlight the significant determinants of ecological footprint for developed countries, developing countries, and the combined sample. The dependent variable in this analysis is ecological footprint, while renewable energy consumption and green finance serve as independent variables. Non-renewable energy consumption and population density are included as control variables. In developed countries, non-renewable energy consumption positively and substantially influences the ecological footprint, indicated by a coefficient of 2.0112. This implies that increasing non-renewable energy consumption by one unit approximately doubles the ecological footprint, reflecting significant environmental degradation associated with such energy sources, as supported by previous studies (Bello et al., 2018; Baloch & Danish, 2022). The statistical significance of this result is confirmed by a high t-statistic of 16.60 and a probability value of 0.0000. In contrast, green finance significantly reduces the ecological footprint by approximately 0.51 units per unit increase, confirmed by its negative coefficient (-0.5127) and strong statistical significance (t-statistic of -2.95, probability value of 0.0033). This aligns with prior findings indicating green finance's effectiveness in environmental protection (Chin et al., 2024; Dong et al., 2023; Campiglio, 2016). Additionally, renewable energy consumption significantly lowers the ecological footprint, reducing it by 0.08 units per unit increase, with robust statistical support (t-statistic of -15.98, probability value of 0.0000), corroborating the environmental benefits of renewable energy (Bashir et al., 2022; Bhowmik et al., 2022). Population density also shows a significant negative relationship with ecological footprint (coefficient of -0.6087), demonstrating that higher population density encourages resource efficiency and sustainable urbanization (Espinosa & Koh, 2024).

For developing countries, non-renewable energy consumption similarly emerges as a major contributor to ecological footprint increase, with a coefficient of 0.8427, significantly supported by statistical evidence (t-statistic of 15.16, probability value of 0.0000). This positive relationship underscores substantial environmental costs linked to non-renewable energy use in these regions (Khan et al., 2019; Lu, 2017). Interestingly, green finance positively influences ecological footprint, increasing it by approximately 0.49 units per unit rise (coefficient of 0.4895), reflecting the transitional phase in developing countries where green investments initially involve high-emission projects (Lee, 2020; Li & Umair, 2023). However, renewable energy consumption shows an insignificant relationship with ecological footprint (coefficient -0.0034, t-statistic of -1.28, probability value of 0.2001), possibly due to limited scale and adoption of renewable energy (Mohamed et al., 2024; Ozcan & Ozturk, 2019). Population density remains significantly negatively correlated (coefficient -0.4049), reaffirming resource efficiency and sustainable urban management as effective in reducing ecological footprints (Karahan-Dursun, 2024; Kumari et al., 2021).

Analyzing the entire sample reveals a substantial positive relationship between non-renewable energy consumption and ecological footprint, increasing by approximately 1.30 units per unit rise (coefficient 1.2988), strongly statistically

ISSN (E) 3007-3197
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Publisher Name : COLLABORATIVE EDUCATIONAL LEARNING INSTITUTE
Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review

VOL-3, ISSUE-3, 2025

significant (t-statistic of 30.99, probability value of 0.0000), emphasizing the global environmental implications of non-renewable energy usage (Idroes et al., 2024; Farhani & Shahbaz, 2014). Similarly, green finance positively correlates with ecological footprint (coefficient 0.4515), highlighting early-stage carbon-intensive infrastructure of green investments (Geddes et al., 2018; Geddes et al., 2020; Dong et al., 2023). Conversely, renewable energy consumption significantly reduces ecological footprint, albeit marginally, by 0.009 units per unit increase (coefficient -0.0087), signifying limited global impact possibly due to slow renewable energy adoption (Farhani & Shahbaz, 2014; Hacıimamoğlu & Cengiz, 2024). Population density retains its negative significant effect (coefficient -0.2996), reaffirming its role in promoting environmental sustainability through efficient urban planning and resource utilization (Hussain et al., 2022; Islami et al., 2022; Espinosa & Koh, 2024).

TABLE 3: PANEL LEAST SQUARES OUTCOMES

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DEVELOPED COUNTRIES				
LNREC	2.011198	0.121176	16.59728	0.0000
GF	-0.512701	0.173834	-2.949372	0.0033
LPD	-0.608718	0.049458	-12.30765	0.0000
REC	-0.077453	0.004846	-15.98453	0.0000
C	-7.204814	1.176691	-6.122945	0.0000
DEVELOPING COUNTRIES				
LNRNC	0.842747	0.055590	15.16017	0.0000
GF	0.489503	0.201148	2.433549	0.0152
RNC	-0.003437	0.002680	-1.282304	0.2001
LPD	-0.404908	0.054039	-7.492849	0.0000
C	-1.447896	0.480389	-3.014009	0.0027
WHOLE SAMPLE				
LNRNC	1.298767	0.041915	30.98597	0.0000
GF	0.451482	0.148203	3.046381	0.0024
RNC	-0.008703	0.002427	-3.585266	0.0003
LPD	-0.302697	0.037346	-8.105273	0.0000
C	-4.530033	0.414339	-10.93315	0.0000

The overall regression outcomes reveal that non-renewable energy consumption is consistently the strongest driver of ecological footprints across developed countries, developing countries, and the whole sample. Renewable energy consumption significantly reduces ecological footprints, particularly in developed countries, highlighting differences in renewable energy adoption levels. Green finance, while beneficial in developed nations, exhibits mixed outcomes in developing nations, emphasizing transitional complexities. Population density consistently emerges as a mitigating factor across all categories, indicating the potential of dense urban areas to promote sustainability effectively. These results underscore critical pathways for targeted policy interventions tailored to regional sustainability contexts.

The generalized method of moments analysis results presented in table 4 provide critical insights into the determinants of ecological footprint for developed countries,

ISSN (E) 3007-3197
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Publisher Name : COLLABORATIVE EDUCATIONAL LEARNING INSTITUTE
Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review

developing countries, and the whole sample. For developed countries, the results reveal that non-renewable energy consumption has a significant positive impact on ecological footprint, increasing the footprint by approximately 2.01 units per additional unit consumed, thus reinforcing the evidence of environmental harm caused by reliance on non-renewable energy sources (Farhani & Shahbaz, 2014; Destek & Sarkodie, 2019; Danish & Wang, 2019; Diaz & Weber, 2020). Green finance demonstrates a negative but marginally significant relationship (coefficient -0.5106, probability value 0.0931), suggesting limited effectiveness possibly due to the initial development stage of green finance initiatives, requiring further policy and capital investments to generate substantial environmental improvements (Chin et al., 2024; Dong et al., 2023; Chenet et al., 2019; Stewart, 2020). Renewable energy consumption significantly reduces ecological footprint, with a negative coefficient (-0.0772) supported by strong statistical evidence (probability value 0.0000), emphasizing its role in environmental protection (Bashir et al., 2022). Population density significantly decreases ecological footprint (coefficient -0.6093, probability value 0.0000), highlighting efficient resource utilization and urban densification as beneficial sustainability strategies (Skhirtladze & Nurboja, 2019; Bakht, 2020; Espinosa & Koh, 2024).

In developing countries, non-renewable energy consumption also significantly increases ecological footprint, with each unit increase causing approximately a 0.84 unit rise (coefficient 0.8446, probability value 0.0000), confirming the environmental costs associated with non-renewable energy dependency (Mohamed et al., 2024). Unlike developed countries, green finance has a significant positive relationship with ecological footprint (coefficient 0.6231), suggesting that current green projects may initially involve environmentally intensive activities, creating short-term ecological harm during transition phases (Toth & Paskal, 2019; Lee, 2020; Turan & Can, 2024; Li & Udemba, 2024). Renewable energy consumption does not exhibit a statistically significant impact (coefficient -0.0034, probability value 0.6693), indicating limited effectiveness, possibly due to the small scale and slower pace of renewable energy implementation (Lu, 2017; Li et al., 2023; Zaim, 2023). Population density again significantly reduces ecological footprint (coefficient -0.4049, probability value 0.0014), demonstrating effective environmental resource management associated with dense urbanization (Karahan-Dursun, 2024; Kumari et al., 2021; Altaf & Shahzad, 2021).

Examining the whole sample, the findings consistently confirm non-renewable energy consumption as a major contributor to ecological footprint, significantly increasing it by approximately 1.30 units per additional unit of energy consumed (coefficient 1.2988, probability value 0.0000), aligning with previous research stressing fossil fuel-induced environmental damage (Anser et al., 2022; Abbas et al., 2021; Apergis & Payne, 2012; Ahmd, 2019; Altıntaş & Kassouri, 2020). Green finance, however, does not significantly affect ecological footprint (coefficient 0.4515, probability value 0.1828), reflecting barriers in immediate environmental outcomes from green financial activities due to delayed impacts and inadequate policy measures (Bai & Lin, 2024; Arshad et al., 2023; Dong et al., 2023; Sheikh & Ahmad, 2020). Similarly, renewable energy consumption has a negative yet insignificant impact (coefficient -0.0087, probability value 0.2106), highlighting procedural delays and infrastructural challenges in fully

ISSN (E) 3007-3197
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Publisher Name : COLLABORATIVE EDUCATIONAL LEARNING INSTITUTE
Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review

realizing renewable energy's environmental potential (Apergis & Payne, 2010; Abbas et al., 2023). Population density significantly reduces ecological footprint (coefficient -0.3027, probability value 0.0008), reinforcing the beneficial impacts of urban density on resource efficiency and sustainability (Ahmed et al., 2020; Alam & Murad, 2020; Chen, 2020).

The overall non-renewable energy consistently emerges as the leading driver of ecological footprint across developed countries, developing countries, and the entire sample. Renewable energy proves effective primarily in developed countries, whereas its impact in developing countries remains limited. Green finance generates mixed effects, negatively impacting ecological footprints in developed nations while positively affecting it in developing countries, reflecting transitional complexities. Population density consistently emerges as an effective tool for environmental sustainability across all regions, underscoring the importance of densely populated urban planning in achieving reduced ecological footprints. These outcomes indicate targeted policy directions for fostering renewable energy adoption, enhancing green finance effectiveness, and promoting sustainable urbanization practices.

TABLE 4: GENERALIZED METHOD OF MOMENTS (GMM) OUTCOMES

DEVELOPED COUNTRIES

DEPENDENT VARIABLE: EFP				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LNREC	2.011955	0.361426	5.566720	0.0000
GF(-2)	-0.510606	0.303707	-1.681245	0.0931
LPD	-0.609322	0.120354	-5.062753	0.0000
REC	-0.077193	0.014741	-5.236538	0.0000
C	-7.215104	2.909874	-2.479525	0.0134
DEVELOPING COUNTRIES				
LNRNC	0.844573	0.170231	4.961333	0.0000
GF (-1)	0.623139	0.370703	1.680966	0.0932
LPD	-0.406761	0.127526	-3.189625	0.0015
RNC	-0.003423	0.007931	-0.431594	0.6662
C	-1.517845	1.290860	-1.175840	0.2400
WHOLE SAMPLE				
LNRNC	1.298767	0.120687	10.76144	0.0000
GF	0.451482	0.338723	1.332893	0.1828
RNC	-0.008703	0.006949	-1.252428	0.2106
LPD	-0.302697	0.089975	-3.364244	0.0008
C	-4.530033	0.931667	-4.862288	0.0000

CONCLUSIONS

This section is comprised of conclusion and policy implications based on estimated results and discussion. This study has examined the impact of green finance and renewable energy consumption on ecological footprint across developed and developing countries from 1995 to 2021. Based on the results and discussions, this study reaches the following conclusions. Estimated results show that non-renewable energy consumption gives positive and exerts a considerable impact on environmental degradation across both

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Publisher Name : COLLABORATIVE EDUCATIONAL LEARNING INSTITUTE
Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review

VOL-3, ISSUE-3, 2025

developed and developing countries. This means that the high utilization of nonrenewable energy sources results to enhanced environmental pollution. The result of the predicted estimation proves that the Renewable energy consumption has a negative and significant impact on the ecological footprint scenario in developed countries, meaning the consumption of renewable energy decreases the environmental impacts. However, the positive impact of this is not very strong in the developing nations where renewable energy projects are still at their initial stages. IFC lifts ecological burden in developed countries while positively correlated in the developing countries in case of green finance. This means that, while green finance reduces ecological footprint in developed countries, development of this financing model is likely to result in increased emissions during the first years of project implementation in developing countries. Population density proves to have a negative and significant effect on the ecological footprint for all the regions, which means that the crowded area uses resources in a better way and have low environmental impact per person. Developing countries should encourage the investment on renewable energy so as to cut need of nonrenewable energy hence reducing impacts on the environment. Governments have a mandate to ensure that the green finance initiatives are appropriately aligned with sustainable development instead of supporting business notional emissions. Local authorities should support approaches that help to concentrate population in the city and minimize the ecological impact. Host countries should find a way of reforming corporate taxes with incentive effects that encourage green investment without reducing FDI in developing nations. Within developed countries it is advised that incentives that are currently represented in form of tax credits for green projects should be increased. Whole countries work together to provide a transfer of renewable energy technology and bibliography of innovative green finance frameworks.

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Frequency Of Journal: Bi-Annual
Annual Methodological Archive Research Review
VOL-3, ISSUE-3, 2025

APPENDIX

TABLE A1: HETEROSKEDASTICITY TEST OUTCOMES DEVELOPED COUNTRIES

chi2(1)	130.23
Prob > chi2	0.0000

TABLE A2: CROSS DEPENDENCY OUTCOMES DEVELOPED COUNTRIES

Variable	CD-test	p-value	correlation	Absolute correlation
EFP	4.960	0.000	0.051	0.423
REC	-1.490	0.135	-0.015	0.456
PD	29.830	0.000	0.306	0.925
GF	55.510	0.006	0.570	0.689
NREC	49.820	0.000	0.512	0.680

TABLE A3: HETEROSKEDASTICITY TEST OUTCOMES DEVELOPING COUNTRIES

$Chi^2(1)$	34.46
Prob > chi^2	0.0000

TABLE A4: CROSS DEPENDENCY OUTCOMES DEVELOPING COUNTRIES

Variable	CD-test	p-value	correlation	Absolute correlation
EFP	32.420	0.000	0.333	0.543
REC	69.870	0.000	0.718	0.778
PD	29.650	0.000	0.305	0.739
GF	2.750	0.006	0.028	0.361
NREC	35.240	0.000	0.362	0.583

TABLE A5: HETEROSKEDASTICITY TEST OUTCOMES WHOLE SAMPLE

chi2(1)	139.99
Prob > chi2	0.0000

TABLE A6: CROSS DEPENDENCY TEST OUTCOMES WHOLE SAMPLE

Variable	CD-test	p-value	Correlation	Absolute correlation
EFP	23.060	0.000	0.117	0.446
REC	29.300	0.000	0.149	0.594
PD	61.310	0.000	0.312	0.829
GF	23.700	0.000	0.121	0.487
NREC	31.190	0.000	0.159	0.506