

Article

Political, Economic and Financial Risks and Environmental Sustainability in Upper–Middle-Income Economies: MMQR Evidence from the Load Capacity Factor

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Abstract

Achieving sustainable economic development remains a major challenge for upper–middle-income countries, where growth dynamics, urbanization, energy demands and institutional risk conditions jointly shape environmental outcomes. This study examines the associations of political risk, economic risk, financial risk, renewable energy consumption, income per capita and urbanization with the load capacity factor (LCF), a sustainability indicator combining biocapacity and ecological footprint. Using a balanced panel of 26 upper–middle-income countries over the period 1994–2020, the analysis estimates three separate specifications in which political, economic and financial risk indicators are examined individually. The Method of Moments Quantile Regression (MMQR) approach is employed to examine heterogeneity in these associations across the conditional distribution of the LCF, while FM-OLS estimates are reported as robustness checks. The findings indicate a U-shaped income–LCF relationship, as economic growth has a negative coefficient, whereas its squared term is positive. Renewable energy consumption is positively associated with the LCF, whereas urbanization is negatively associated with it. Higher political risk index scores, indicating lower political risk, are positively associated with the LCF. By contrast, higher economic and financial risk index scores, indicating lower risk levels, are associated with lower LCFs, particularly at the middle and upper quantiles. The results highlight the need to combine renewable energy transition, sustainable urban planning, institutional stability and environmentally oriented financial policies.

Keywords: load capacity factor; environmental sustainability; political risk; economic risk; financial risk; renewable energy; urbanization; MMQR; upper–middle-income countries



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1. Introduction

Reconciling economic development with environmental sustainability has become a central challenge in environmental economics. Climate change, ecological overshoot, resource depletion and the weakening of regenerative ecological capacity indicate that growth-oriented development strategies cannot be evaluated independently of environmental limits (Ni et al., 2022; Raihan et al., 2026). Environmental performance should therefore be assessed not only through measures of ecological pressure, such as carbon dioxide emissions and ecological footprint, but also in relation to ecosystems' regenerative capacity. The load

capacity factor (LCF), defined as the ratio of biocapacity to ecological footprint, addresses this need by indicating whether the ecological demand remains within nature's regenerative capacity; values above one indicate an ecological surplus, whereas values below one indicate an ecological deficit (Henni et al., 2026; Ni et al., 2022; Raihan et al., 2026). This broader perspective is particularly useful for examining the political, economic and financial conditions under which growth can be made compatible with ecological sustainability (Idris et al., 2025; Rong et al., 2024).

This question is particularly relevant for upper-middle-income countries. These economies have generally moved beyond the severe capacity constraints associated with low-income countries but have not yet fully reached the technological, institutional and environmental standards associated with high-income economies. At the same time, they face rapid urban expansion, rising energy demands, industrial restructuring, financial deepening and greater exposure to domestic and external macroeconomic shocks (Latif & Faridi, 2023; Ni et al., 2022). Middle-income countries also account for a large share of the global population, output and carbon emissions, making upper-middle-income countries a policy-relevant setting for examining the determinants of environmental sustainability (World Bank, 2024).

Existing LCF research identifies income, renewable energy consumption, urbanization, natural resource use, technological progress and institutional quality as interrelated determinants of environmental sustainability (Henni et al., 2026; Idris et al., 2025). Renewable energy consumption is generally expected to improve the LCF by reducing fossil fuel dependence and supporting cleaner production structures (Ge & Mehmood, 2024; U. Khan et al., 2022). Urbanization may reduce the LCF through higher energy demands, transport intensity, land use pressure and infrastructure expansion, although effective infrastructure and sustainable planning may mitigate these adverse effects (Guloglu et al., 2023; Sevinç et al., 2025; Sugiharti et al., 2025). Within the Load Capacity Curve (LCC) framework, income may initially reduce the LCF by increasing ecological pressure but may improve environmental quality after a certain threshold through cleaner technologies, stronger regulation and greater environmental awareness (Arjun & Mishra, 2025; Guloglu et al., 2023).

These determinants, however, operate within political, macroeconomic and financial conditions. Lower political risk may strengthen regulatory continuity, institutional enforcement and policy credibility while supporting long-term green investment, although political stability may also sustain resource-intensive development strategies (Dam et al., 2023; Eyuboglu & Uzar, 2025; X. Li et al., 2023; C. Sun et al., 2024; Xu et al., 2024; Yong et al., 2024). Lower economic risk may facilitate long-term investment in renewable energy, clean technologies and ecological infrastructure, but its environmental implications depend on the development strategy enabled by macroeconomic stability (K. A. Khan et al., 2025a; Latif & Faridi, 2023; Ojekemi et al., 2023; Rong et al., 2024; Wu et al., 2023). Similarly, financial stability may either support environmental sustainability by directing resources toward renewable energy, green technologies and energy efficiency or intensify ecological pressure by expanding credit, investment and consumption in energy-intensive sectors. Its environmental implications therefore depend on the direction of financial allocation and the institutional framework within which financial resources are mobilized (Anas et al., 2024; Javed et al., 2025; Latif & Faridi, 2023; S. Li et al., 2024; Özbay et al., 2024; Pata & Samour, 2023; K. Zhang & Jia, 2025; Zhao et al., 2023).

Despite the growing LCF literature, it remains unclear whether political, economic and financial risk dimensions have similar environmental implications. Previous studies have often examined these dimensions separately, indirectly or in different country settings, making it difficult to compare their relationships with the LCF within a common environmental sustainability framework (K. A. Khan et al., 2025a; Rong et al., 2024). This limitation is

particularly relevant to upper–middle-income countries, which face simultaneous pressures from economic expansion, urbanization, energy demands and institutional transformation yet have received relatively limited attention as a distinct and policy-relevant group, as much of the literature has focused on BRICS, OECD, G7, E7, OIC and regional samples (Idris et al., 2025; U. Khan et al., 2022; Özbay et al., 2024). Moreover, because much of the existing evidence relies on mean-based estimators, it provides limited insight into whether the relationships between the LCF and income per capita, renewable energy consumption, urbanization and risk indicators differ across relatively low, medium and high levels of environmental performance (Byaro et al., 2024; Latif & Faridi, 2023; Ojekemi et al., 2023). Accordingly, there remains a need for comparative evidence of whether political, economic and financial risk dimensions are associated with the LCF in distinct ways and whether these relationships vary across the conditional distribution of the LCF.

Against this background, this study examines the associations between political, economic and financial risk indicators and the LCF in 26 upper–middle-income countries over the period 1994–2020, while controlling for income per capita, its squared term, renewable energy consumption and urbanization. The three risk indicators are examined in separate model specifications using the same set of control variables, allowing their relationships with the LCF to be estimated and compared on a common basis. In addition, the inclusion of income per capita and its squared term allows the study to test the validity of the Load Capacity Curve hypothesis in the selected upper–middle-income countries.

The main contribution of this study lies in the comparative assessment of political, economic and financial risk within the LCF literature. By comparing the three risk dimensions within a consistent empirical setting, the study examines whether different forms of stability are associated with higher or lower environmental performance. A second contribution is distributional: the study examines whether these relationships vary across the lower, middle and upper quantiles of the conditional LCF distribution, thereby identifying patterns that may be concealed by mean-based estimates (Byaro et al., 2024; Idris et al., 2025; Rong et al., 2024). The MMQR approach provides the analytical framework for this distributional assessment, while the sample of upper–middle-income countries offers a policy-relevant setting in which rapid economic transformation, urbanization, financial development and environmental pressures coexist.

Accordingly, this study seeks to answer the following research questions: do political, economic and financial risk dimensions have similar associations with the LCF in selected upper–middle-income countries, and do these associations—together with those of renewable energy consumption, urbanization and income per capita—vary across the conditional distribution of the LCF?

The remainder of the article is organized as follows. Section 2 reviews the relevant empirical literature. Section 3 presents the data, variables and model specification. Section 4 explains the econometric methodology. Section 5 reports the empirical findings and complementary analyses. Section 6 discusses the findings and policy implications, and Section 7 concludes.

2. Literature Review

The literature on environmental sustainability has increasingly shifted from single-dimensional indicators, such as carbon emissions, toward more comprehensive measures that capture both ecological pressure and ecological capacity. In this context, the load capacity factor (LCF) has gained importance as an indicator that combines the ecological footprint and biocapacity, thereby providing a broader perspective on environmental quality. Existing studies generally examine the determinants of the LCF by considering economic growth, the energy structure, urbanization, institutional quality and financial

conditions. However, the effects of these determinants may differ across country groups, development levels and methodological approaches. Therefore, Section 2 reviews the relevant literature by focusing on five main channels: economic growth, renewable energy consumption, urbanization, political risk and economic and financial risks.

2.1. Economic Growth and LCF

The relationship between economic growth and the LCF operates through two opposing channels and is therefore not necessarily unidirectional. On the one hand, economic expansion may increase industrial production, fossil fuel-based energy demands, natural resource use, consumption and land use pressure. These processes can enlarge the ecological footprint and place additional pressure on biocapacity, thereby reducing the LCF. On the other hand, higher income levels may facilitate technological upgrading, cleaner production, a transition toward renewable energy, stronger environmental regulation and greater environmental awareness, all of which may improve the LCF (Guloglu et al., 2023; W. Wang et al., 2024). This dual mechanism provides the theoretical basis for examining the growth–LCF relationship within a nonlinear rather than a purely linear framework.

The Load Capacity Curve (LCC) hypothesis formalizes this nonlinear relationship by predicting a U-shaped association between income and the LCF. Economic growth may initially reduce the LCF as production, energy consumption and ecological pressure increase; beyond a certain income threshold, however, further growth may improve environmental sustainability through cleaner technologies, more efficient production structures and stronger environmental policies. Accordingly, empirical studies generally include both income and its squared term to capture the transition between these opposing effects (Alharbey & Ben-Salha, 2024; Arjun & Mishra, 2025; Guloglu et al., 2023). A substantial part of the literature supports the LCC hypothesis across global and income-based samples; OECD, G-7 and G-8 economies; BRICS-T; selected Asian economies; and country groups including upper–middle-income economies (Arjun & Mishra, 2025; Ayad & Djedaïet, 2024; Byaro et al., 2024; Guloglu et al., 2023; Imran et al., 2025; Javed et al., 2025; K. A. Khan et al., 2025a, 2025b; Sarabdeen et al., 2024; Soto, 2024; W. Wang et al., 2024; Wu et al., 2023; Yong et al., 2024). Quantile-based studies further show that the estimated turning points vary across the conditional distribution of the LCF, suggesting that the income level required for environmental improvement may depend on a country’s relative position in the conditional distribution of the LCF (Arjun & Mishra, 2025; Imran et al., 2025).

However, the empirical evidence is not uniform. Several studies have found that economic growth continues to reduce the LCF, particularly when expansion is driven by energy-intensive production, fossil fuel dependence, industrial activity or natural resource use. Such findings were reported for lower-middle- and upper–middle-income OIC economies, BRICS countries, China and Brazil (Adebayo & Ullah, 2023; Ergene et al., 2025; Faizi et al., 2025; Kirikkaleli & Adebayo, 2024; M. Yang et al., 2023). Other studies have identified nonlinear patterns that are different from the standard U-shaped LCC, including N-shaped and inverted-U-shaped relationships, or found no evidence supporting the hypothesis in developing countries, European economies and leading renewable energy-consuming countries (Ayad et al., 2023; Bucak & Çatık, 2026; Caglar et al., 2026; Idris et al., 2025; Ozkan et al., 2025). Studies examining the EKC and LCC frameworks together also indicate that the estimated income–environment relationship depends on the environmental indicator employed. Ecological footprint is more commonly associated with an inverted U-shaped relationship, whereas the LCF is more frequently linked to a U-shaped pattern (Arjun & Mishra, 2025; Hacıimamoglu, 2025; Soto & Edeh, 2024; Q. Wang et al., 2025; Kong et al., 2025).

Taken together, the literature suggests that the effect of economic growth on the LCF is determined not by income expansion alone but by the structural characteristics of the growth process. Growth is more likely to reduce the LCF when it expands fossil fuel-based production, energy demands and resource use, whereas it may improve the LCF when additional income supports technological upgrading, cleaner energy systems and stronger environmental governance. Differences across countries and quantiles may therefore reflect variations in energy structure, technological capacity, institutional effectiveness and the sectoral composition of growth. This theoretical ambiguity justifies the inclusion of both income and its squared term in the empirical model, as well as the examination of their effects across the conditional distribution of the LCF.

2.2. Renewable Energy and LCF

Renewable energy consumption may improve the LCF primarily through the substitution, efficiency and ecological pressure channels. Replacing fossil fuels with renewable sources can reduce carbon-intensive energy production, resource extraction and the ecological footprint, while cleaner technologies and more efficient production structures can ease the pressure on ecosystems' regenerative capacity. However, an increase in renewable energy consumption does not automatically produce an equivalent improvement in the LCF. Its environmental contribution depends on whether renewable energy effectively displaces fossil fuel use, as well as on technological capacity, energy infrastructure, regulatory effectiveness and access to long-term financing. Where renewable energy merely supplements rather than replaces conventional energy, or where weak infrastructure and institutional constraints limit its effective deployment, the resulting environmental gains may remain modest. The renewable energy–LCF relationship may therefore vary across countries and across different points of the conditional LCF distribution.

A large body of empirical evidence supports the positive effect of renewable energy on the LCF. Studies covering OECD and G-11 countries have generally found that renewable energy reduces ecological pressure and improves environmental sustainability, although the magnitude of the effect varies across quantiles and model specifications (Fatima et al., 2025; Ge & Mehmood, 2024; Guloglu et al., 2023; Özbay et al., 2024; Pata & Samour, 2023). Similar evidence was reported for BRICS, E-7 and broader emerging and developing country groups, where renewable energy consumption, green innovation and policies supporting the energy transition were generally associated with higher LCFs (Adebayo & Samour, 2023; Afshan & Yaqoob, 2023; Alam et al., 2025; Bekun et al., 2025; Erdogan & Akalin, 2025; Huang et al., 2025; U. Khan et al., 2022; S. Li et al., 2024; F. Liu & Sander, 2026; Ojekemi et al., 2023; Qin & Conti, 2026; Wu et al., 2023). Country-specific evidence from Türkiye, Portugal, Poland and Thailand also generally supports the environmental benefits of renewable energy (Deka, 2025; Henni et al., 2026; Özkan et al., 2025; Pata et al., 2024b; Raihan, 2025; Raihan et al., 2024). Studies examining specific renewable technologies further showed that solar, wind, biofuel, hydroelectricity and renewable electricity could improve the LCF, particularly when combined with green finance, green technology and human capital (Karlilar Pata & Pata, 2025; B. Li et al., 2025; Nwani & Omoke, 2025; Samour et al., 2023; Xu et al., 2024).

Nevertheless, the magnitude and direction of the renewable energy effect are not uniform. Quantile-based studies have found that its positive contribution increases toward higher quantiles in some country groups but declines across the LCF distribution in others, indicating that the effectiveness of renewable energy may depend on countries' relative environmental positions and structural characteristics (F. Liu & Sander, 2026; Ojekemi et al., 2023; Pata & Samour, 2023; Wu et al., 2023). Evidence from Asian countries further highlights the complementary role of institutions and political conditions. Renewable

energy was more effective in improving the LCF when accompanied by institutional quality, political stability, lower geopolitical uncertainty, reduced corruption and stronger bureaucratic capacity (K. A. Khan et al., 2024; W. Wang et al., 2024; Xu et al., 2024; Zhou & Javed, 2026). Byaro et al. (2024), for example, found that renewable energy alone reduced the LCF across most quantiles, whereas its interaction with institutional quality improved environmental sustainability. Similarly, Annor et al. (2024) reported that renewable energy negatively affected the LCF when considered independently but became environmentally beneficial when combined with financial market development. Negative renewable energy effects were also reported for Malaysia and China, showing that increases in renewable energy use may be insufficient when they do not generate effective substitution away from environmentally intensive energy and production structures (Altıntaş et al., 2024; Z. Yang et al., 2026).

Taken together, the literature indicates that renewable energy generally improves the LCF but that its environmental contribution is conditional on the broader technological, institutional and financial setting in which the energy transition occurs. Renewable energy is more likely to strengthen environmental sustainability when it replaces fossil fuel consumption, is supported by adequate energy infrastructure and receives effective regulatory and financial support. Conversely, its contribution may remain limited or become adverse when renewable deployment is inefficient, when the conventional energy demand continues to expand or when institutional and financial constraints prevent the transition from producing meaningful ecological gains. Differences across countries and quantiles may therefore reflect variations in fossil fuel substitution, technological capacity, institutional effectiveness, financial support and countries' relative positions within the conditional distribution of the LCF. These heterogeneous effects and their underlying mechanisms justify examining the effect of renewable energy across different quantiles rather than relying exclusively on mean-based estimates.

2.3. Urbanization and LCF

Urbanization may affect the LCF through opposing environmental pressure and efficiency channels. Rapid urban expansion increases the demands for housing, transportation, energy, water and infrastructure, while land use change and the conversion of agricultural or forest areas into urban settlements may enlarge the ecological footprint and reduce the biocapacity (Guloglu et al., 2023; Raihan, 2025). These pressures may become stronger when urbanization is accompanied by industrial concentration, construction activity, fossil fuel-based energy use and pollution-intensive production (Dai et al., 2025; Teng et al., 2024). Conversely, efficient infrastructure, sustainable transport, renewable energy systems and effective urban planning may reduce the ecological costs of population concentration. The effect of urbanization on the LCF therefore depends not only on the growth of the urban population but also on the production, consumption, transport and energy use patterns associated with urban expansion (Fang et al., 2024; Pata & Ertugrul, 2023).

A substantial part of the empirical literature reports a negative relationship between urbanization and the LCF. Evidence from major nuclear power economies, the United States, China, Thailand and India indicates that urbanization increases energy and infrastructure pressures and weakens environmental sustainability (X. Liu et al., 2025; Pata & Ertugrul, 2023; Raihan, 2025; Sevinç et al., 2025; Teng et al., 2024). Panel studies covering OECD, European, ASEAN and Asian economies have similarly found that urbanization reduces the LCF, although the magnitude of the adverse effect varies across country groups and quantiles (Caglar et al., 2025; Fang et al., 2024; Guloglu et al., 2023; Imran et al., 2025). Guloglu et al. (2023) found that the negative effect became relatively strong toward the upper quantiles, whereas Imran et al. (2025) reported that it was more pronounced at the

middle quantiles. Evidence from G-7 countries and Thailand further shows that the adverse environmental effect of urbanization intensifies when urban growth occurs together with industrial expansion and fossil fuel-based energy use (Dai et al., 2025; Raihan, 2025).

Nevertheless, the empirical evidence is not uniform. Degirmenci et al. (2025) found that urbanization improved the LCF in China and Brazil but reduced it in Mexico, indicating that its environmental consequences vary even among countries with broadly similar development characteristics. Similarly, Sugiharti et al. (2025) reported a positive effect of urbanization on the LCF in ASEAN countries, with a relatively strong contribution at the lower and middle quantiles. These findings suggest that urbanization could support environmental sustainability when population concentration is accompanied by efficient infrastructure, cleaner energy systems, sustainable transportation and effective urban planning. They also indicate that the direction and magnitude of the urbanization effect depend on country-specific structural conditions and countries' relative positions within the conditional distribution of the LCF.

Overall, the literature indicates that the relationship between urbanization and the LCF is heterogeneous and context-dependent. Urbanization is more likely to reduce the LCF when it intensifies the energy demand, infrastructure pressure, land conversion and pollution-intensive activities, whereas efficient infrastructure, clean energy systems, sustainable transport and effective urban planning may mitigate or even reverse this effect. Therefore, in the present study, urbanization is included as a key explanatory variable to examine whether urban expansion places pressure on environmental sustainability in upper-middle-income countries and whether this effect differs across the conditional distribution of the LCF.

2.4. Political Risk and LCF

Political risk may affect the LCF primarily through environmental governance, regulatory credibility, institutional enforcement and investment uncertainty. Although many studies do not employ a comprehensive political risk index directly, they have examined closely related dimensions such as political and government stability, geopolitical risk, policy uncertainty, institutional quality, the rule of law, bureaucratic quality and control of corruption. These dimensions represent different channels through which political conditions may influence environmental sustainability. Lower political risk can improve policy continuity, strengthen the enforcement of environmental regulations and reduce uncertainty surrounding long-term investments in renewable energy and clean technologies. However, political stability does not automatically improve the LCF if stable institutions support resource-intensive production or prioritize economic expansion over environmental protection. Its environmental effect therefore depends on how political and institutional stability is translated into regulatory action and development policy.

A substantial part of the empirical literature supports the environmental benefits of political stability and stronger governance. Studies covering European countries, N-11 economies, ASEAN countries, Brazil, Malaysia and China have generally found that political or government stability improves the LCF, whereas higher political risk weakens environmental sustainability (Adebayo & Ullah, 2023; Fang et al., 2024; Kiliç Depren et al., 2024; Kirikkaleli & Adebayo, 2024; X. Li et al., 2023; X. Q. Sun et al., 2024). Governance-related evidence similarly shows that lower corruption, stronger bureaucratic quality, good governance, the rule of law and institutional quality support the LCF by strengthening policy implementation and institutional capacity (Faizi et al., 2025; Ni et al., 2022; Qing et al., 2025; Xu et al., 2024). Nevertheless, the effects of specific institutional and freedom-related indicators are not uniform. Fu and Blake (2026) found that fiscal discipline, the rule of law and business freedom improved the LCF, whereas the tax burden, property

rights, investment freedom and financial freedom reduced it. [Senturk et al. \(2025\)](#) likewise reported heterogeneous effects of institutional freedom indicators across MENA countries.

Geopolitical risk and policy uncertainty represent additional channels through which political conditions may affect the LCF. Higher geopolitical risk can discourage long-term green investment, disrupt energy markets and encourage a shift toward readily available fossil fuel-based energy sources. Consistent with this mechanism, studies covering BRICS-T, Asian countries and India have generally found that geopolitical risk and global uncertainty reduce the LCF, although the magnitude of the effect differs across quantiles and environmental indicators ([K. A. Khan et al., 2025a](#); [Ramzan et al., 2025](#); [Villanthenkodath & Pal, 2024](#)). However, [Pata et al. \(2024a\)](#) reported heterogeneous country- and quantile-specific effects, finding that geopolitical risk increased the LCF at the lower and middle quantiles in Brazil, South Africa and Türkiye but reduced ecological quality at higher quantiles. Policy uncertainty produces a more consistently adverse pattern. Economic, energy and climate policy uncertainty generally reduce the LCF by weakening policy predictability and distorting investment incentives, particularly at lower quantiles, whereas institutional quality improves environmental sustainability ([K. A. Khan et al., 2025b](#); [Pata, 2025](#); [Wu et al., 2023](#)).

Overall, the literature indicates that political risk influences the LCF through interconnected governance, enforcement, policy predictability and investment channels. Political stability is more likely to improve environmental sustainability when it strengthens regulatory credibility, institutional capacity and long-term commitment to environmental policy. Conversely, geopolitical tensions, policy uncertainty and weak enforcement may reduce the LCF by discouraging green investment and disrupting the clean energy transition. The direction and magnitude of these effects may nevertheless vary according to the political risk dimension considered, the institutional and economic context and the position within the conditional distribution of the LCF. Therefore, the present study includes the political risk index in a separate model specification to examine whether lower political risk contributes to environmental sustainability in upper-middle-income countries and whether this relationship differs across quantiles.

2.5. Economic Risk, Financial Risk and LCF

Economic and financial risks may affect the LCF through distinct but interconnected transmission mechanisms. Economic risk primarily operates through macroeconomic stability, production expansion and the energy demand. Greater macroeconomic stability can reduce uncertainty and support long-term investments in renewable energy, clean technologies and ecological infrastructure. At the same time, it may accelerate production, consumption and energy demands, thereby increasing ecological pressure when economic expansion remains dependent on fossil fuels and resource-intensive activities. Financial risk operates mainly through financing conditions, credit allocation and the sectoral direction of investment. Greater financial stability may improve the LCF when financial resources are directed toward renewable energy, energy efficiency and cleaner production, but it may reduce the LCF when easier financing expands credit, consumption and investment in energy- and resource-intensive sectors. Because higher economic and financial risk index scores indicate lower levels of risk, their environmental effects depend not simply on whether stability increases but on whether the resulting stability supports green transformation or conventional growth-oriented expansion.

Direct empirical evidence based on economic and financial risk indices remains limited and mixed. For BRICS countries, [Ojekemi et al. \(2023\)](#) found that higher economic and financial risk index scores improved the LCF and that their marginal effects increased toward the upper quantiles. [Adebayo \(2023\)](#) similarly reported that financial risk and economic complexity positively affected the LCF in BRICS countries. However, the two

risk dimensions do not always produce similar environmental outcomes. [Rong et al. \(2024\)](#) showed that a higher economic risk index improved the LCF in China, whereas a higher financial risk index reduced it. [Awosusi and Uzun \(2025\)](#) likewise found that financial risk negatively affected the LCF in Brazil and that the adverse effect became stronger at higher quantiles. These contrasting findings suggest that macroeconomic stability and financial stability could affect environmental sustainability differently depending on the energy structure, financial allocation and country-specific development dynamics.

The broader financial development literature provides additional evidence regarding the credit allocation and investment direction channels, although financial development should not be treated as equivalent to a financial risk index. Several studies have reported that financial development reduces the LCF, a pattern that is consistent with the expansion of credit, consumption, investment and energy demands without corresponding reallocation toward environmentally sustainable activities. Negative effects have been reported for OECD, BRICS, BRICS-T and Asian economies, as well as for Japan and the United States ([Awosusi et al., 2024](#); [Latif & Faridi, 2023](#); [S. Li et al., 2024](#); [Özbay et al., 2024](#); [Ridwan et al., 2024](#); [Zhao et al., 2023](#)). [Latif and Faridi \(2023\)](#), however, showed that strong institutions could transform the adverse effects of financial development, foreign direct investment and economic growth into positive environmental outcomes. Other studies have reported positive or heterogeneous effects of financial development, a pattern that is consistent with the view that financial institutions and markets may improve the LCF when resources are directed toward cleaner technologies, renewable energy and more efficient production. Such positive or heterogeneous effects have been reported for E-7 countries, the United States, China, selected Asian countries and Malaysia ([Adebayo et al., 2025](#); [Altıntaş et al., 2024](#); [Degirmenci et al., 2025](#); [Ergene et al., 2025](#); [W. Wang et al., 2024](#)). Taken together, this evidence indicates that the environmental effect of financial development depends less on the scale of finance alone than on its institutional quality and the sectors toward which financial resources are allocated.

The literature on green finance, climate finance and green investment further clarifies the importance of the direction of financial allocation. Green finance generally improved environmental quality in Türkiye, Brazil, E-7 countries and selected developing economies by supporting renewable energy, green technology and low-carbon investment ([Anas et al., 2024](#); [Dinghong et al., 2025](#); [Kirikkaleli & Adebayo, 2024](#); [Yardımcı & Oskay, 2025](#)). Positive effects were also reported for green investment in G-7 countries and green financial development in APEC economies ([Javed et al., 2025](#); [Kong et al., 2025](#)). Nevertheless, the evidence is not entirely uniform. [Tekin et al. \(2025\)](#) found that climate finance reduced the LCF in OECD countries, while [Jiang et al. \(2024\)](#) reported that green financial development adversely affected the LCF in Asian countries unless it was combined with environmental technologies. These findings suggest that financial instruments labeled as green do not automatically improve environmental sustainability unless they effectively support technological upgrading and low-carbon transformation. Evidence concerning public debt, external debt, fiscal shocks and monetary policy similarly shows that their environmental effects depend on how public and financial resources are allocated and whether policy supports green transformation or conventional production and consumption ([Adebayo & Samour, 2023](#); [Ali et al., 2025b](#); [Arjun & Mishra, 2025](#); [K. Zhang & Jia, 2025](#)).

Overall, the literature does not support a unidirectional relationship between economic and financial stability and environmental sustainability. The environmental consequences of lower economic and financial risks depend on whether macroeconomic stability and financial deepening support green transformation or expand resource-intensive production, consumption and energy demands. These competing mechanisms are particularly relevant for upper-middle-income countries, where macroeconomic stabilization and financial

deepening do not necessarily coincide with green structural transformation (Destek et al., 2024; Tekin et al., 2025; Jiang et al., 2024). The present study examines economic risk and financial risk in separate model specifications to identify their distinct relationships with the LCF and to determine whether these relationships vary across different quantiles of the conditional LCF distribution.

2.6. Summary of the Review of the Literature

The reviewed literature suggests that the determinants of the LCF operate through distinct but interconnected mechanisms. Economic growth, renewable energy consumption, urbanization and country risk are associated with environmental sustainability through different channels, and their environmental implications depend on the broader institutional and development context rather than on any single factor in isolation. Prior studies have generally found that renewable energy improves the LCF by reducing the dependence on fossil fuels, whereas the environmental consequences of economic growth and urbanization depend largely on production structures, technological progress, the energy composition and environmental governance.

The reviewed evidence further indicates that country risk is multidimensional and that different forms of stability do not necessarily have uniform environmental implications. Political risk is primarily associated with environmental governance, regulatory credibility and institutional enforcement, all of which could facilitate the implementation of long-term environmental policies and support green investment. By contrast, economic risk mainly operates through macroeconomic stability, production conditions and the energy demand, whereas financial risk is more closely related to credit allocation and the direction of investment. Consequently, greater economic or financial stability could either improve the LCF by supporting green transformation or weaken it by facilitating resource- and energy-intensive expansion.

The empirical evidence also shows that these relationships are not uniform across countries or levels of environmental performance. Although many studies have reported broadly similar average relationships, others have found heterogeneous results depending on the country characteristics, institutional quality, development stage and estimation method. This evidence suggests that mean-based estimates could conceal important distributional differences and that the environmental implications of political, economic and financial risks need to be examined comparatively within a common analytical framework.

Accordingly, this study examines political, economic and financial risk indicators in separate model specifications and employs the Method of Moments Quantile Regression (MMQR) approach to determine whether their relationships with the LCF differ across the conditional distribution of environmental sustainability. This approach allows the study to assess whether the three dimensions of country risk carry different environmental implications across the lower, middle and upper parts of the conditional LCF distribution.

3. Data and Model Specification

3.1. Data and Variables

According to the World Bank FY26 income classification, 54 economies were classified as upper-middle-income economies and were initially considered for inclusion in the analysis (World Bank, 2025). The final sample was determined by the joint availability of data from the Global Footprint Network, the World Development Indicators and the International Country Risk Guide (ICRG). To be included, an economy was required to have complete annual observations for all study variables over the common period 1994–2020. Applying these criteria resulted in a balanced panel of 26 economies: Argentina, Armenia, Botswana, Brazil, China, Colombia, Cuba, Dominican Republic, Ecuador, El Salvador,

Equatorial Guinea, Gabon, Guatemala, Indonesia, Iran, Iraq, Jamaica, Libya, Malaysia, Mexico, Mongolia, Paraguay, Peru, South Africa, Thailand and Türkiye.

The balanced panel was used to maintain a common observation period, ensure that each economy contributed the same number of observations and avoid changes in sample composition over time due to intermittent missing data. This structure improved the comparability of the estimates across economies and quantiles. However, the balanced panel requirement also imposed a stricter data availability requirement and contributed to the reduction of the initial sample from 54 to 26 economies. The remaining 28 economies were excluded because at least one of the required data conditions could not be satisfied. The principal reasons were the absence of ecological footprint or biocapacity data, the lack of country coverage for one or more of the ICRG risk indicators and missing World Development Indicator observations that prevented the construction of a complete common-period panel. Some economies had data from one or two of these sources but lacked complete observations across all variables and data sources.

Although the risk indicators were available beyond 2020 for the economies covered by the PRS Group's ICRG database, the study period was determined by the longest common period over which all variables could be combined consistently across the three data sources. Since data availability may not be random across economies, the final sample may relatively overrepresent countries with more developed statistical reporting systems. Whether this pattern also reflects broader differences in institutional capacity could not be assessed directly. Accordingly, the findings primarily apply to the 26 economies included in the sample and should be generalized to all upper-middle-income economies with appropriate caution.

The data are obtained from three main sources. The LCF is calculated using biocapacity and ecological footprint data obtained from the Global Footprint Network. Data on income per capita, measured by the GDP per capita in constant 2015 US dollars, as well as renewable energy consumption and urbanization are obtained from the World Bank World Development Indicators. Political, economic and financial risk indicators are taken from the PRS Group's International Country Risk Guide (ICRG) database. The definitions, measurements and data sources for these variables are presented in Table 1.

Table 1. Description of variables.

Variable	Measurement	Source
Load capacity factor (LCF)	Ratio of biocapacity (global hectares per capita) to ecological footprint (global hectares per capita)	(GFN, 2025)
Political risk (PR)	Political risk index ranging from 0 to 100 and consisting of 12 subcomponents; higher values indicate lower political risk	(PRS Group, 2023)
Economic risk (ER)	Economic risk index ranging from 0 to 50 and consisting of 5 subcomponents; higher values indicate lower economic risk	(PRS Group, 2023)
Financial risk (FR)	Financial risk index ranging from 0 to 50 and consisting of 5 subcomponents; higher values indicate lower financial risk	(PRS Group, 2023)
Renewable energy consumption (REC)	Renewable energy consumption as a percentage of total energy consumption	(World Bank, 2023)
Urbanization (URB)	Urban population as a percentage of total population	(World Bank, 2023)
Economic growth (EG)	Gross domestic product per capita, constant 2015 US dollars	(World Bank, 2023)

3.2. Model Specification

The empirical analysis is based on three baseline model specifications. Political, economic and financial risks represent conceptually distinct dimensions of country risk and

may influence environmental sustainability through different transmission mechanisms. Political risk is primarily associated with environmental governance, regulatory credibility and institutional enforcement, whereas economic risk mainly operates through macroeconomic stability, production expansion and the energy demand. Financial risk, in turn, is related to financing conditions, credit allocation and the sectoral direction of investment. Accordingly, each risk dimension is initially examined in a separate specification, while the remaining explanatory variables are kept identical across the models. This design allows the associations of the three risk dimensions with the LCF to be compared transparently within a common empirical framework.

The separate specifications are retained as the baseline models because they facilitate the comparative interpretation of the three conceptually distinct risk dimensions under an identical set of control variables. However, estimating the risk indicators separately does not show whether their coefficient patterns persist when the other risk dimensions are controlled for. To address this issue, an additional MMQR specification including political, economic and financial risk simultaneously is estimated as a model specification sensitivity analysis. The separate and joint specifications therefore serve complementary purposes: the baseline models provide a clear comparative assessment of each risk dimension, whereas the joint model evaluates whether the principal findings remain when the shared influences of the other risk dimensions are taken into account. The general form of the empirical model can be expressed as follows:

$$LCF_{it} = f\left(EG_{it}, EG_{it}^2, REC_{it}, URB_{it}, RISK_{it}\right) \quad (1)$$

where i indexes countries, t indexes years and $RISK_{it}$ denotes political, economic or financial risk, depending on the specification. Accordingly, the three empirical models are specified as follows.

Political Risk Model (PR Model):

$$\ln LCF_{it} = \alpha_i + \beta_1 \ln EG_{it} + \beta_2 (\ln EG_{it})^2 + \beta_3 \ln REC_{it} + \beta_4 \ln URB_{it} + \beta_5 \ln PR_{it} + \varepsilon_{it} \quad (2)$$

Economic Risk Model (ER Model):

$$\ln LCF_{it} = \alpha_i + \beta_1 \ln EG_{it} + \beta_2 (\ln EG_{it})^2 + \beta_3 \ln REC_{it} + \beta_4 \ln URB_{it} + \beta_5 \ln ER_{it} + \varepsilon_{it} \quad (3)$$

Financial Risk Model (FR Model):

$$\ln LCF_{it} = \alpha_i + \beta_1 \ln EG_{it} + \beta_2 (\ln EG_{it})^2 + \beta_3 \ln REC_{it} + \beta_4 \ln URB_{it} + \beta_5 \ln FR_{it} + \varepsilon_{it} \quad (4)$$

All variables included in the analysis, including the dependent variable, are transformed into natural logarithmic form before estimation. This transformation reduces distortions arising from differences in measurement scale and helps to obtain a more stable variance structure. It also limits the influence of extreme observations, thereby improving the reliability of the parameter estimates. In addition, the log–log model specification allows the coefficients to be interpreted in elasticity terms and provides a clearer understanding of how proportional changes in economic growth, urbanization, renewable energy consumption and risk indicators are associated with changes in the LCF (Guloglu et al., 2023; Latif & Faridi, 2023; Özbay et al., 2024; Pata & Samour, 2023; Zhou & Javed, 2026).

4. Methodology

Section 4 presents the econometric strategy employed in the study. The empirical analysis is carried out in several stages. First, the Hausman test is applied to determine whether

the fixed-effects or random-effects specification is more appropriate for the panel models. Second, cross-sectional dependence and slope heterogeneity are examined to determine whether the panel structure is characterized by interdependence across countries and heterogeneous slope coefficients. Third, the stationarity of the variables is investigated using the CIPS panel unit root test, which accounts for cross-sectional dependence. Fourth, panel cointegration tests are conducted to examine whether a long-run relationship exists among the variables. After these pre-estimation analyses, the Method of Moments Quantile Regression (MMQR) approach is employed as the main estimation strategy to examine whether the associations between the explanatory variables and LCF vary across the conditional distribution. Following the MMQR estimations, diagnostic tests for heteroskedasticity and autocorrelation are conducted to assess the error structure of the baseline models. FM-OLS estimates are then reported as complementary long-run evidence, and an additional joint MMQR specification is estimated as a model specification sensitivity analysis. The empirical analyses were conducted using R version 4.4.1 via RStudio, Stata 17 and EViews 12.

Method of Moments Quantile Regression

In this study, the Method of Moments Quantile Regression (MMQR) approach, developed by Machado and Santos Silva (2019), is employed as the main estimation strategy. Quantile regression provides a richer framework than mean-based estimators because it allows the relationship between the dependent variable and its covariates to be examined at different points of the conditional distribution. This is particularly relevant for the present study, since the associations of income per capita, renewable energy consumption, urbanization and risk indicators with the LCF may vary across the lower, middle and upper quantiles of the conditional LCF distribution.

Conventional fixed-effects and random-effects panel estimators were not adopted as the main estimation methods because they would characterize the relationships between the explanatory variables and LCF only at the conditional mean. Although these estimators account for unobserved country-specific heterogeneity under different assumptions, they cannot reveal whether the estimated associations differ across the lower, middle and upper parts of the conditional LCF distribution. This limitation is particularly important for the present study, whose central research question concerns distributional heterogeneity in the environmental associations of political, economic and financial risk. In addition, the Hausman test rejects the random-effects specification, indicating that country-specific effects are correlated with the explanatory variables. MMQR was therefore preferred because it accommodates unobserved country heterogeneity while providing quantile-specific coefficient estimates through its location–scale framework. Thus, the Hausman test supports a fixed-effects treatment of country-specific heterogeneity relative to random effects, whereas MMQR extends the analysis beyond the conditional mean and directly addresses the distributional objective of the study.

In panel quantile models, the treatment of unobserved individual effects is a central methodological issue. Unlike the standard fixed-effects mean regression model, fixed-effects quantile regression does not allow for a simple within transformation that removes individual effects from the model. Therefore, the direct inclusion of individual effects may give rise to an incidental parameter problem, particularly in panels with a limited time dimension. The panel quantile literature has addressed this issue through different strategies, including Koenker's (2004) longitudinal quantile regression framework, Lamarche's (2010) penalized fixed-effects approach and Canay's (2011) two-step estimator. In contrast, the MMQR approach relies on a location–scale specification in which unobserved individual heterogeneity is captured through both the location and scale components of the conditional distribution (Machado & Santos Silva, 2019).

The MMQR model can be written as follows:

$$Y_{it} = \alpha_i + X'_{it}\beta + (\delta_i + Z'_{it}\gamma)U_{it} \quad (5)$$

where Y_{it} denotes the dependent variable, X'_{it} is the vector of explanatory variables in the location equation and Z'_{it} is the vector of covariates specified in the scale equation. α_i denotes the individual location effect, while δ_i represents the individual scale effect. The vectors β and γ refer to the location and scale parameters, respectively. U_{it} is an unobserved standardized random component, not a conventional additive error term. It is assumed to be independent of the explanatory variables and normalized through moment conditions. Under this structure, the conditional quantile function is expressed as

$$Q_{Y_{it}}(\tau | X_{it}, Z_{it}) = [\alpha_i + \delta_i q(\tau)] + X'_{it}\beta + Z'_{it}\gamma q(\tau) \quad (6)$$

Here, $q(\tau)$ denotes the τ -th quantile of U_{it} . Thus, MMQR allows individual heterogeneity to affect not only the location of the conditional distribution of the LCF but also its scale. In this way, the method provides a suitable framework for examining whether economic growth, renewable energy consumption, urbanization and risk indicators have heterogeneous effects across different quantiles of the conditional distribution of the LCF.

5. Empirical Findings

5.1. Descriptive Statistics

Before proceeding to the econometric estimations, descriptive statistics are presented to provide an overview of the main characteristics of the variables used in the analysis. Descriptive statistics are reported for the variables in their original levels before logarithmic transformation. Table 2 reports the mean, median, maximum, minimum, standard deviation, skewness, kurtosis and Jarque–Bera statistics for the variables.

Table 2. Descriptive statistics.

Statistic	LCF	PR	ER	FR	URB	REC	EG
Mean	1.56	62.41	36.98	33.46	64.00	27.65	5531.18
Median	0.58	63.42	37.42	34.58	65.40	20.77	5038.85
Maximum	24.25	79.42	48.83	46.75	92.11	90.12	14,200.27
Minimum	0.16	31.75	5.54	9.21	29.18	0.31	562.32
Std. Dev.	2.68	8.59	6.60	6.09	14.95	23.67	2842.64
Skewness	4.87	−0.88	−1.37	−1.00	−0.39	0.95	0.78
Kurtosis	31.56	4.12	7.03	4.55	2.50	2.94	3.37
Jarque–Bera	26,623.53	127.79	696.98	187.74	24.85	104.62	75.41
Prob.	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Observations	702	702	702	702	702	702	702

According to Table 2, the LCF distribution is strongly right-skewed, as indicated by its positive skewness value. The large difference between the minimum and maximum values of the LCF also points to substantial variation across countries and years in the study sample. The mean values of the political, economic and financial risk indices are 62.41, 36.98 and 33.46, respectively. Since higher values of these indices indicate lower levels of risk, it can be stated that the upper-middle-income countries included in the study exhibit moderate levels of political, economic and financial stability on average. The mean value of urbanization is 64.00, indicating that a considerable share of the population in upper-middle-income countries lives in urban areas. The mean value of renewable energy consumption is 27.65. However, the large difference between its minimum and maximum

values suggests that renewable energy use varies considerably across countries and over time. In addition, the GDP per capita ranges from 562.32 to 14,200.27, indicating notable differences in income levels within the dataset. The Jarque–Bera statistics are statistically significant at the 1% level for all variables, indicating that the variables do not follow a normal distribution. The pronounced skewness and dispersion motivate the examination of distributional heterogeneity in addition to mean-based relationships.

Because political, economic and financial risk represent related dimensions of country risk, the pairwise correlations among the logarithmic risk indicators were also examined. Table 3 reports the correlation coefficients between political risk, economic risk and financial risk.

Table 3. Pairwise correlations among the risk indicators.

Variable Pair	Correlation Coefficient
Political Risk–Economic Risk	0.2576 ^a
Political Risk–Financial Risk	0.2671 ^a
Economic Risk–Financial Risk	0.7814 ^a

Notes: Correlations were calculated using the logarithmic forms of the risk indicators; ^a $p < 0.01$.

As shown in Table 3, political risk is positively but relatively modestly correlated with economic risk ($r = 0.2576$) and financial risk ($r = 0.2671$). By contrast, the correlation between economic and financial risk is comparatively high ($r = 0.7814$), indicating that these two indicators contain a substantial degree of shared variation. This pattern is consistent with political risk capturing a relatively distinct institutional dimension, whereas economic and financial stability are more closely interconnected. However, pairwise correlations alone do not determine the appropriate model specification or necessarily imply problematic multicollinearity. The separate models are retained primarily for conceptual comparison, while the relatively high correlation between economic and financial risk indicates that their coefficients may be estimated with lower precision when they are included simultaneously. For this reason, the joint MMQR model is reported as a complementary sensitivity analysis rather than as a replacement for the baseline specifications.

Figure 1 presents the average LCF values of the 26 upper–middle-income countries included in the study sample over the period 1994–2020. The red horizontal line represents the threshold value of 1, which distinguishes ecological surplus from ecological deficit. Countries with average LCF values above 1 exhibit an ecological surplus, indicating that their available biocapacity exceeds their ecological footprint. In contrast, countries with average LCF values below 1 experience an ecological deficit, implying that their ecological demand exceeds their available biocapacity.

5.2. Pre-Estimation Results

Before examining cross-sectional dependence and other pre-estimation properties, the Hausman test is applied to determine whether the fixed-effects or random-effects specification is more appropriate for the panel models. The null hypothesis of the Hausman test states that the individual effects are not correlated with the explanatory variables; in this case, the random-effects estimator is consistent and efficient. Rejection of the null hypothesis indicates that the individual effects are correlated with the regressors and that the fixed-effects specification is more appropriate (Hausman, 1978). Table 4 reports the Hausman test results for the PR, ER and FR model specifications.

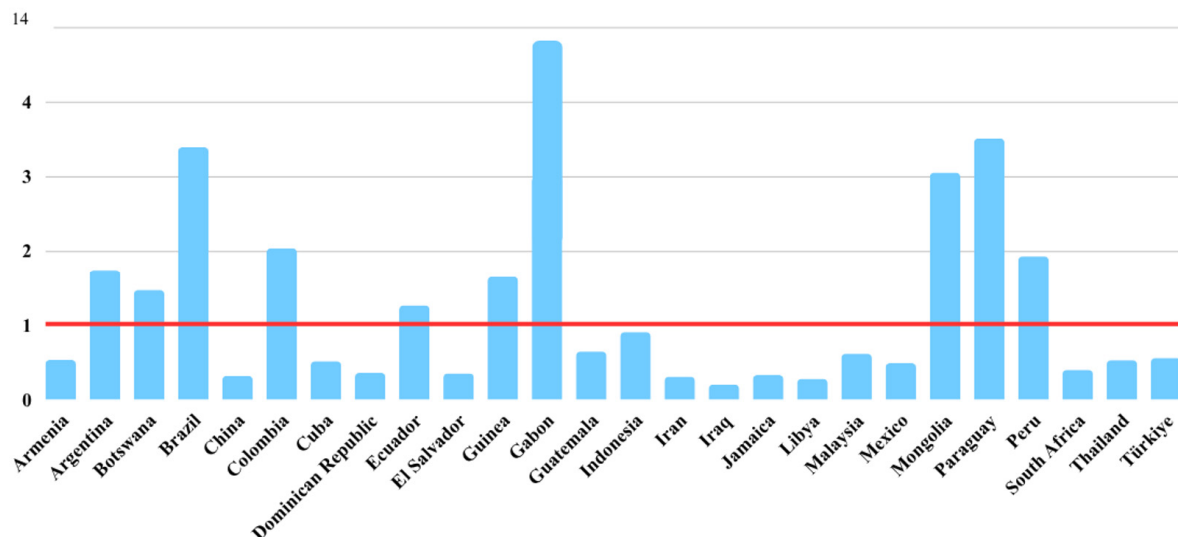


Figure 1. Average load capacity factor by country, 1994–2020.

Table 4. Hausman test results.

Model	Chi-Square Stat.	df	<i>p</i> -Value	Decision	Preferred Model
ER model	21.871	5	0.0006	H ₀ rejected	Fixed effects
FR model	22.002	5	0.0005	H ₀ rejected	Fixed effects
PR model	21.224	5	0.0007	H ₀ rejected	Fixed effects

As reported in Table 4, the Hausman test results reject the null hypothesis for all three model specifications at the 1% significance level. This indicates that the individual effects are correlated with the explanatory variables and that the random-effects specification is not appropriate. Therefore, the fixed-effects specification is preferred for the PR, ER and FR models. This result also confirms the importance of controlling for unobserved country-specific heterogeneity in the empirical analysis.

After determining the appropriateness of the fixed-effects specification, cross-sectional dependence is examined. In panel data analysis, the assumption that cross-sectional units are independent may be restrictive, particularly when countries are exposed to common economic, financial, political or environmental shocks. Global energy price fluctuations, financial crises, trade linkages and international policy spillovers may create interdependence across countries. Ignoring cross-sectional dependence may lead to biased test statistics, unreliable standard errors and misleading inference in panel data models (Baltagi, 2015). Therefore, cross-sectional dependence is tested using the Breusch–Pagan LM, Pesaran scaled LM, bias-corrected scaled LM and Pesaran CD tests. These tests differ in terms of their suitability for different panel dimensions. While the Breusch–Pagan LM test is generally more appropriate when T is relatively large and N is relatively small, the Pesaran CD test is based on average pairwise correlations and performs well in panels with relatively large N and small T . The bias-corrected scaled LM test is also used to improve the small-sample properties of LM-type tests (Pesaran, 2015). The null hypothesis of these tests assumes cross-sectional independence. The results are presented in Table 5.

The results reported in Table 5 strongly reject the null hypothesis of cross-sectional independence for all variables. The test statistics are statistically significant at the 1% level in all tests. This finding indicates the presence of cross-sectional dependence among the countries in the sample. In other words, shocks affecting one country may also be transmitted to other countries through economic, financial, energy-related or environmental

channels. Therefore, the use of second-generation panel unit root tests that account for cross-sectional dependence is justified.

Table 5. Cross-sectional dependence test results.

Parameter	Breusch–Pagan LM	Pesaran Scaled LM	Bias-Corrected Scaled LM	Pesaran CD
lnLCF	3429.89 ^a	121.29 ^a	121.28 ^a	44.95 ^a
lnPR	2941.83 ^a	102.64 ^a	102.14 ^a	37.18 ^a
lnER	3144.39 ^a	110.58 ^a	110.08 ^a	32.28 ^a
lnFR	2859.38 ^a	99.4 ^a	98.91 ^a	30.86 ^a
lnEG	2301.91 ^a	77.54 ^a	77.04 ^a	15.12 ^a
(lnEG) ²	2312.55 ^a	77.95 ^a	77.45 ^a	15.77 ^a
lnREC	3202.1 ^a	112.84 ^a	112.34 ^a	36.91 ^a
lnURB	2136.89 ^a	71.06 ^a	70.56 ^a	9.55 ^a

^a $p < 0.01$.

After testing for cross-sectional dependence, slope homogeneity is examined. In panel data models, assuming homogeneous slope coefficients across countries may be restrictive, particularly when countries differ in terms of economic structure, energy composition, urbanization dynamics and institutional conditions (Baltagi, 2015). In this context, Swamy's S, Delta and adjusted Delta tests are used to examine slope homogeneity. Swamy's S test was developed for panels in which N is relatively small compared with T , and Swamy's S statistic asymptotically follows a chi-squared distribution under the null hypothesis. Pesaran and Yamagata proposed the Delta test for large N and T , as well as the adjusted Delta statistic, which corrects for small-sample bias. The null hypothesis assumes slope homogeneity, whereas the alternative hypothesis indicates that slope coefficients differ across cross-sectional units (Pesaran, 2015). The results are reported in Table 6.

Table 6. Slope homogeneity test results.

Model	Delta	Adj. Delta	Swamy S
PR	20.581 ^a	23.913 ^a	150,000 ^a
ER	19.432 ^a	22.578 ^a	150,000 ^a
FR	19.901 ^a	23.122 ^a	160,000 ^a

^a $p < 0.01$.

As reported in Table 6, the Swamy's S, Delta and adjusted Delta statistics are statistically significant at the 1% level for all three model specifications. Therefore, the null hypothesis of slope homogeneity is rejected for the PR, ER and FR models. This result indicates that the slope coefficients differ across countries, implying that the effects of economic growth, renewable energy consumption, urbanization and risk indicators on the LCF are not homogeneous across the sample.

Considering the presence of cross-sectional dependence and slope heterogeneity, the stationarity of the variables is examined using the CIPS panel unit root test, which is regarded as a second-generation panel unit root test. Unlike first-generation panel unit root tests, the CIPS approach extends the standard ADF regression by including the cross-sectional averages of the lagged level and first-differenced variables. In this way, cross-sectional dependence arising from common shocks is accounted for. The CIPS statistic is obtained by averaging the CADF statistics calculated for each cross-sectional unit and provides an aggregated panel-level unit root test result. The null hypothesis of the CIPS test states that the series contains a unit root, whereas the rejection of the null hypothesis indicates stationarity (Pesaran, 2007). The results are reported in Table 7.

Table 7. CIPS unit root test results.

Variable	CIPS Test Statistic (Level)			CIPS Test Statistic (First Difference)		
	With Constant	Without Constant	With Constant and Trend	With Constant	Without Constant	With Constant and Trend
lnLCF	−1.795	0.0315	−2.233	−2.651 ^a	−2.294 ^a	−3.509 ^a
lnPR	−1.408	−1.845 ^a	−1.594	−2.709 ^a	−2.749 ^a	−2.846 ^a
lnER	−1.499	−1.519 ^c	−1.838	−3.713 ^a	−3.613 ^a	−3.385 ^a
lnFR	−2.111 ^c	−2.258 ^b	−1.722	−3.897 ^a	−3.538 ^a	−3.593 ^a
lnEG	−1.751	−1.384	−1.963	−3.503 ^a	−2.871 ^a	−2.995 ^a
(lnEG) ²	−1.823	−1.227	−1.939	−3.298 ^a	−2.736 ^a	−2.881 ^a
lnREC	−1.756	−1.842 ^a	−1.571	−3.111 ^a	−3.455 ^a	−2.827 ^a
lnURB	−1.036	3.023	−2.747 ^b	−3.168 ^a	−2.417 ^a	−3.366 ^a

^a $p < 0.01$, ^b $p < 0.05$, ^c $p < 0.1$.

The CIPS test results reported in Table 7 indicate that the variables do not exhibit consistent evidence of stationarity in levels. Although some variables appear to be stationary under certain deterministic specifications, this evidence does not persist across all deterministic component choices. However, the CIPS statistics for the first-differenced series are statistically significant at the 1% level for all variables, indicating that the variables become stationary after first differencing. Therefore, the variables are generally considered to be integrated of order one, $I(1)$.

After the unit root analysis, the Westerlund panel cointegration test is employed to examine whether there is a long-run equilibrium relationship among the variables. Unlike residual-based cointegration tests, this test is based on the error correction mechanism and directly tests whether the error correction term is statistically different from zero (Westerlund, 2007). The test provides four statistics: two group-mean statistics, G_τ and G_α , and two panel statistics, P_τ and P_α . The group-mean statistics test the alternative hypothesis that cointegration exists for at least one cross-sectional unit, whereas the panel statistics test the alternative that cointegration exists for the panel as a whole. Since the previous findings indicate the presence of cross-sectional dependence, the robust probability values obtained through the bootstrap procedure are also considered in the interpretation (Persyn & Westerlund, 2008; Westerlund, 2007). The Westerlund cointegration test results are reported in Table 8.

Table 8. Westerlund cointegration test results.

Model	Statistic	Value	p -Value	Robust p -Value
PR	G_τ	−3.987 ^a	0.000	0.000
	G_α	−7.726	0.996	0.157
	P_τ	−16.473 ^a	0.000	0.000
	P_α	−7.126	0.719	0.129
ER	G_τ	−3.986 ^a	0.000	0.000
	G_α	−7.513	0.997	0.214
	P_τ	−17.029 ^a	0.000	0.000
	P_α	−5.984	0.905	0.343
FR	G_τ	−4.139 ^a	0.000	0.000
	G_α	−7.034	0.999	0.293
	P_τ	−14.46 ^a	0.000	0.000
	P_α	−6.138	0.888	0.236

^a $p < 0.01$.

As reported in Table 8, the Westerlund cointegration test results provide evidence of a long-run relationship among the variables in all three model specifications. In the PR, ER and FR models, both the G_τ and P_τ statistics are statistically significant at the 1% level. Moreover, the robust probability values of these statistics are also equal to 0.000, confirming the rejection of the null hypothesis of no cointegration. Although the G_α and P_α statistics are not statistically significant, the significance of G_τ and P_τ provides evidence in favor of cointegration. In the related literature, the rejection of the null hypothesis by at least one group statistic and one panel statistic is commonly interpreted as supporting the existence of cointegration among the variables (Ahmed & Le, 2021; Arshad et al., 2020; Şeker et al., 2025; Vural, 2021; L. Wang et al., 2023; Zhou & Javed, 2026). Therefore, the results provide sufficient evidence to support the existence of a long-run cointegration relationship among the variables in the PR, ER and FR models.

Taken together, the pre-estimation results directly inform the empirical strategy. The Hausman test establishes the need to control for country-specific effects rather than relying on the random-effects assumption. The evidence of cross-sectional dependence justifies the use of the second-generation CIPS unit root test and the bootstrap probability values of the Westerlund cointegration test. The rejection of slope homogeneity indicates that the assumption of identical slope coefficients across countries is restrictive and that pooled estimates should be interpreted with appropriate caution. The finding that the variables are generally integrated of order one makes it necessary to establish cointegration before interpreting relationships estimated in levels, while the evidence of cointegration supports the use of FM-OLS as a complementary long-run estimator.

5.3. MMQR Results

After the pre-estimation tests, the MMQR results are reported for three alternative model specifications: the political risk model, the economic risk model and the financial risk model. In each model, the location and scale coefficients are first presented, followed by the quantile-specific estimates from the 10th to the 90th quantiles. This structure allows the associations of income per capita, renewable energy consumption, urbanization and risk indicators with the LCF to be examined across different points of the conditional distribution. Table 9 reports the MMQR estimation results for the political, economic and financial risk models.

As reported in Table 9, the results provide strong evidence that the estimated associations of the determinants of the LCF vary across quantiles. In all three models, the coefficient of log income per capita ($\ln EG$) is negative and statistically significant across all quantiles, while the coefficient of the squared logarithmic income term, $(\ln EG)^2$, is positive and statistically significant. Moreover, the absolute magnitudes of both coefficients generally decline toward the upper quantiles. Taken together, these coefficients are consistent with a U-shaped income–LCF relationship whose estimated pattern varies across the conditional distribution. Because income per capita enters the model through both $\ln EG$ and $(\ln EG)^2$, its marginal association with the LCF depends jointly on the two coefficients and the level of income per capita, rather than on the coefficient of $\ln EG$ alone. These findings are consistent with the LCC hypothesis.

Renewable energy consumption is positively associated with the LCF in all three model specifications. In the political risk model, its coefficient is positive and statistically significant from the lower to the middle quantiles, while statistical significance weakens at the upper quantiles. In the economic risk model, the coefficient remains positive and statistically significant across all quantiles. In the financial risk model, the positive association is also evident, particularly from the lower to the middle quantiles, although the coefficient magnitude decreases toward the upper quantiles. These findings indicate that

the renewable energy–LCF association is positive but not uniform across the conditional distribution. The estimated positive coefficient is relatively large at the lower quantiles and gradually decreases toward the upper quantiles.

Table 9. MMQR estimation results.

Political Risk Model						
	Constant	lnEG	(lnEG) ²	lnREC	lnURB	lnPR
Location	10.5365 ^a	−2.0299 ^a	0.1121 ^a	0.0655 ^a	−0.6226 ^a	0.1903 ^b
Scale	0.6267	0.0584	−0.0003	−0.0175	−0.1855 ^a	−0.0437
q10	9.6422 ^a	−2.1132 ^a	0.1126 ^a	0.0905 ^a	−0.3579 ^a	0.2527 ^a
q20	9.8854 ^a	−2.0906 ^a	0.1124 ^a	0.0837 ^a	−0.4299 ^a	0.2357 ^a
q30	10.0513 ^a	−2.0751 ^a	0.1124 ^a	0.0791 ^a	−0.4790 ^a	0.2242 ^a
q40	10.2426 ^a	−2.0573 ^a	0.1123 ^a	0.0737 ^a	−0.5356 ^a	0.2108 ^a
q50	10.4948 ^a	−2.0338 ^a	0.1121 ^a	0.0667 ^a	−0.6103 ^a	0.1932 ^b
q60	10.7591 ^a	−2.0092 ^a	0.1120 ^a	0.0593 ^b	−0.6885 ^a	0.1748 ^b
q70	10.9951 ^a	−1.9872 ^a	0.1119 ^a	0.0527 ^b	−0.7583 ^a	0.1584 ^c
q80	11.2654 ^a	−1.9620 ^a	0.1117 ^a	0.0452	−0.8383 ^a	0.1395
q90	11.5571 ^a	−1.9349 ^a	0.1116 ^a	0.0371	−0.9247 ^a	0.1192
Economic Risk Model						
	Constant	lnEG	(lnEG) ²	lnREC	lnURB	lnER
Location	9.9257 ^a	−1.5730 ^a	0.0893 ^a	0.0806 ^a	−0.7631 ^a	−0.0806 ^c
Scale	−0.6529	0.3481	−0.0148	−0.0026	−0.1784 ^a	−0.1067 ^a
q10	10.8611 ^a	−2.0718 ^a	0.1104 ^a	0.0843 ^a	−0.5074 ^a	0.0723
q20	10.6275 ^a	−1.9473 ^a	0.1052 ^a	0.0834 ^a	−0.5713 ^a	0.0341
q30	10.4437 ^a	−1.8492 ^a	0.1010 ^a	0.0827 ^a	−0.6215 ^a	0.0041
q40	10.2097 ^a	−1.7245 ^a	0.0957 ^a	0.0817 ^a	−0.6855 ^a	−0.0342
q50	9.9383 ^a	−1.5798 ^a	0.0896 ^a	0.0806 ^a	−0.7596 ^a	−0.0785 ^c
q60	9.6887 ^a	−1.4467 ^a	0.0839 ^a	0.0796 ^a	−0.8279 ^a	−0.1193 ^b
q70	9.4247 ^a	−1.3059 ^a	0.0779 ^a	0.0785 ^a	−0.9000 ^a	−0.1624 ^a
q80	9.1655 ^a	−1.1677 ^b	0.0721 ^b	0.0775 ^b	−0.9709 ^a	−0.2048 ^a
q90	8.8635 ^a	−1.0066 ^c	0.0652 ^b	0.0762 ^b	−1.0534 ^a	−0.2541 ^a
Financial Risk Model						
	Constant	lnEG	(lnEG) ²	lnREC	lnURB	lnFR
Location	10.4749 ^a	−1.7042 ^a	0.0967 ^a	0.0720 ^a	−0.7350 ^a	−0.1012 ^b
Scale	0.1141	0.1349	−0.0040	−0.0157	−0.1093 ^b	−0.1053 ^a
q10	10.3126 ^a	−1.8960 ^a	0.1024 ^a	0.0944 ^a	−0.5795 ^a	0.0487
q20	10.3533 ^a	−1.8480 ^a	0.1010 ^a	0.0888 ^a	−0.6185 ^a	0.0111
q30	10.3840 ^a	−1.8117 ^a	0.0999 ^a	0.0846 ^a	−0.6479 ^a	−0.0172
q40	10.4268 ^a	−1.7610 ^a	0.0984 ^a	0.0786 ^a	−0.6890 ^a	−0.0568
q50	10.4687 ^a	−1.7116 ^a	0.0969 ^a	0.0729 ^a	−0.7291 ^a	−0.0954 ^b
q60	10.5185 ^a	−1.6527 ^a	0.0951 ^a	0.0660 ^a	−0.7768 ^a	−0.1414 ^a
q70	10.5696 ^a	−1.5923 ^a	0.0933 ^a	0.0589 ^b	−0.8258 ^a	−0.1886 ^a
q80	10.6126 ^a	−1.5415 ^a	0.0918 ^a	0.0530 ^c	−0.8669 ^a	−0.2282 ^a
q90	10.6625 ^a	−1.4826 ^a	0.0901 ^a	0.0461	−0.9147 ^a	−0.2743 ^a

^a $p < 0.01$, ^b $p < 0.05$, ^c $p < 0.10$. Statistical significance is based on heteroskedasticity-robust standard errors computed using the Huber–White sandwich estimator.

Urbanization is negatively and statistically significantly associated with the LCF across all models and quantiles. Furthermore, the absolute magnitude of the negative coefficient generally increases toward the upper quantiles. This pattern indicates that the negative urbanization–LCF association becomes more pronounced in the upper segments of the conditional distribution, where the conditional LCF is relatively high.

Before interpreting the risk coefficients, it should be noted that higher values of the ICRG indices indicate lower levels of political, economic and financial risk. Since both the LCF and the risk indicators are expressed in natural logarithms, the estimated coefficients can be interpreted as elasticities. Accordingly, a positive coefficient indicates that a reduction in the relevant risk is associated with a higher LCF, whereas a negative coefficient indicates that a reduction in risk is associated with a lower LCF. The interpretations below focus primarily on the quantiles at which the coefficients are statistically significant.

The political risk index has a positive coefficient across all quantiles, with the statistically significant relationship concentrated between q10 and q70. Since a higher PR score indicates lower political risk, the positive coefficients show that lower political risk is associated with a higher LCF. At q10, the coefficient is 0.2527, implying that a 1% increase in the political risk index—corresponding to a reduction in political risk—is associated with an approximately 0.25% increase in the LCF. Although the coefficient remains positive throughout the distribution, its magnitude gradually decreases and it becomes statistically insignificant at q80 and q90. The results therefore indicate that the positive association between lower political risk and the LCF is more clearly observed in the lower and middle parts of the conditional LCF distribution.

The economic risk index exhibits a different quantile pattern. Its coefficients are positive but statistically insignificant at the lower quantiles, including values of 0.0723 at q10 and 0.0341 at q20. Therefore, the estimates do not provide evidence of a statistically significant relationship between economic risk and the LCF in the lower part of the conditional distribution. The coefficient becomes negative from q40 onward and statistically significant from q50, declining from -0.0785 at the median to -0.2541 at q90. Since a higher ER score indicates lower economic risk, these negative coefficients mean that lower economic risk is associated with a lower LCF in the middle and upper parts of the conditional distribution. At q90, for example, a 1% increase in the economic risk index is associated with an approximately 0.25% decrease in the LCF. The increasing absolute magnitude of the coefficient toward the upper quantiles indicates that the negative association becomes more pronounced in the upper part of the conditional LCF distribution. This result does not imply that economic instability improves environmental sustainability. Rather, it indicates that improved macroeconomic risk conditions do not necessarily translate into ecological gains in the middle and upper parts of the conditional LCF distribution.

The financial risk index displays a broadly similar quantile pattern, although it represents a conceptually distinct dimension of risk. Its coefficients are positive but statistically insignificant at q10 and q20, with values of 0.0487 and 0.0111, respectively. The coefficient becomes negative from q30 onward and statistically significant from q50, declining from -0.0954 at the median to -0.2743 at q90. Since a higher FR score indicates lower financial risk, the statistically significant negative coefficients show that lower financial risk is associated with a lower LCF in the middle and upper parts of the conditional distribution. At q90, a 1% increase in the financial risk index—corresponding to a reduction in financial risk—is associated with an approximately 0.27% decrease in the LCF. The increase in the absolute magnitude of the coefficient toward the upper quantiles indicates that this negative association becomes stronger in the upper part of the conditional distribution. This result does not imply that financial instability improves environmental sustainability. Rather, it indicates that improved financial risk conditions do not necessarily translate into ecological gains in the middle and upper parts of the conditional LCF distribution.

Overall, the MMQR results confirm that the estimated effects of the determinants of the LCF differ across quantiles. The associations of income per capita, renewable energy consumption, urbanization and risk indicators with the LCF vary across the conditional distribution. The findings highlight the positive role of renewable energy consumption,

the adverse environmental effect of urbanization, the supportive contribution of improved political stability and institutional conditions and the more complex environmental implications of reductions in economic and financial risk.

5.4. Diagnostic and Complementary Analyses

In addition to the main MMQR estimates, diagnostic tests, a complementary long-run estimation and a model specification sensitivity analysis are conducted to assess the reliability of the empirical findings. First, heteroskedasticity and autocorrelation diagnostics are examined to evaluate the error structures of the baseline models. Second, FM-OLS is employed as a complementary long-run estimator to examine whether the main coefficient signs and relationships are consistent within a cointegration framework. Third, political, economic and financial risk are included simultaneously in an additional MMQR specification to assess whether the results obtained from the separate risk models are sensitive to the exclusion of the other risk dimensions. Since the separate MMQR specifications remain the main empirical models, the FM-OLS estimates provide complementary evidence of the average long-run relationships, whereas the joint MMQR results are interpreted as a model specification sensitivity analysis.

5.4.1. Diagnostic Test Results

Before reporting the robustness estimates, heteroskedasticity and autocorrelation diagnostics are examined to evaluate the error structures of the baseline fixed-effects models. First, groupwise heteroskedasticity is tested using the modified Wald test, which is commonly applied in fixed-effects panel models. The null hypothesis of the test states that the error variance is constant across cross-sectional units, whereas the alternative hypothesis indicates that the error variances differ across units. Unlike some conventional LR, LM and Wald-type tests that rely more strongly on the normality assumption, the modified Wald test can be applied asymptotically even when the normality assumption is violated (Baum, 2000; Greene, 2003). Second, first-order autocorrelation is examined using the HR test developed by Born and Breitung (2016). This test is designed for fixed-effects panel models and is robust to heteroskedasticity. The null hypothesis of the HR test states that there is no first-order autocorrelation in the error term. Since the modified Wald results indicate the presence of heteroskedasticity, the use of a heteroskedasticity-robust autocorrelation test is appropriate. Born and Breitung (2016) and Wursten (2018) show that the HR test performs well under heteroskedasticity compared with several alternative autocorrelation tests. The results of the modified Wald and HR tests are presented in Table 10.

Table 10. Heteroskedasticity and autocorrelation diagnostic test results.

Model	Modified Wald Statistic	<i>p</i> -Value	HR Statistic	<i>p</i> -Value
PR	1542.84 ^a	0.000	−0.80	0.422
ER	2026.83 ^a	0.000	−0.73	0.465
FR	2113.35 ^a	0.000	−0.82	0.415

^a *p* < 0.01.

As reported in Table 10, the modified Wald statistics are statistically significant at the 1% level for all three specifications. The null hypothesis of homoskedasticity is therefore rejected, indicating the presence of groupwise heteroskedasticity in the baseline fixed-effects representations of the PR, ER and FR models. By contrast, the HR statistics are not statistically significant, and the null hypothesis of no first-order autocorrelation cannot be rejected in any of the three specifications. These diagnostic tests characterize the error structures of the baseline panel models rather than serving as direct specification tests of the MMQR or FM-OLS estimators. Nevertheless, the presence of heteroskedasticity indicates

that statistical inference based on conventional homoskedastic standard errors could be misleading. Accordingly, inference for the MMQR estimates is based on heteroskedasticity-robust standard errors computed using the Huber–White sandwich estimator, whereas inference for the FM-OLS estimates is based on a sandwich covariance matrix allowing for heterogeneous variances, with a degrees-of-freedom adjustment. Thus, the reported significance levels for both estimators do not rely on the assumption of constant error variance. The absence of statistically significant first-order autocorrelation also reduces concerns regarding this particular form of serial dependence in the baseline models.

5.4.2. Robustness Check

Following the diagnostic tests, FM-OLS estimates are reported as a robustness check. Since the pre-estimation results indicate the existence of a long-run cointegration relationship among the variables, FM-OLS provides an appropriate framework for examining whether the main coefficient signs obtained from the MMQR analysis are consistent in the long run. Unlike MMQR, which captures heterogeneous effects across different quantiles of the conditional distribution, FM-OLS provides average long-run coefficient estimates. Therefore, consistent with the approach adopted in the related literature, the FM-OLS estimates are interpreted not as alternatives to the main MMQR findings but as complementary evidence of the robustness of the estimated relationships (Adebayo, 2023; Ali et al., 2025a; Arjun & Mishra, 2025; Hammami et al., 2025; Ojekemi et al., 2023; Y. Zhang et al., 2025). The FM-OLS estimation results are presented in Table 11.

Table 11. Robustness check results: FM-OLS estimates.

Model	lnEG	(lnEG) ²	lnREC	lnURB	lnPR	lnER	lnFR
PR	−2.4210 ^a (0.4713)	0.1342 ^a (0.0285)	0.0502 ^b (0.0231)	−0.5606 ^a (0.1552)	0.2650 ^a (0.0921)	−	−
ER	−1.8366 ^a (0.4468)	0.1054 ^a (0.0260)	0.0739 ^a (0.0234)	−0.7518 ^a (0.1476)	−	−0.0971 ^b (0.0419)	−
FR	−1.9328 ^a (0.4723)	0.1104 ^a (0.0284)	0.0639 ^a (0.0224)	−0.6753 ^a (0.1375)	−	−	−0.0874 ^c (0.0514)

^a $p < 0.01$, ^b $p < 0.05$, ^c $p < 0.10$. Heteroskedasticity-robust sandwich standard errors with a degrees-of-freedom adjustment are reported in parentheses.

As reported in Table 11, the FM-OLS results are broadly consistent with the main MMQR findings. Since all variables are expressed in natural logarithms, the estimated coefficients can be interpreted as long-run elasticities. Accordingly, the FM-OLS estimates indicate that renewable energy consumption has a positive and statistically significant effect on the LCF in all three models. A 1% increase in renewable energy consumption increases the LCF by approximately 0.05% in the PR model, 0.07% in the ER model and 0.06% in the FR model. This finding supports the view that renewable energy consumption contributes positively to environmental quality.

Urbanization has a negative and statistically significant effect on the LCF across all model specifications. The coefficient of urbanization is −0.5606 in the PR model, −0.7518 in the ER model and −0.6753 in the FR model. These results imply that a 1% increase in urbanization reduces the LCF by approximately 0.56%, 0.75% and 0.68%, respectively. Therefore, the FM-OLS findings confirm that urbanization creates considerable pressure on environmental sustainability in upper-middle-income countries.

The coefficients of economic growth are negative and statistically significant in all three models, whereas the coefficients of squared economic growth are positive and statistically significant. This pattern supports the existence of a nonlinear relationship between

economic growth and the LCF. In other words, the environmental effect of economic growth is not linear, which is consistent with the MMQR results.

Regarding the risk indicators, the political risk coefficient is positive and statistically significant in the PR model. Since higher PR values indicate lower political risk, this result suggests that improved political stability and institutional conditions contribute positively to the LCF. By contrast, the coefficients of economic risk and financial risk are negative and statistically significant in the ER and FR models, respectively. Since higher ER and FR values indicate lower economic and financial risks, these findings suggest that improvements in economic and financial risk conditions do not necessarily translate into better environmental quality.

Although the FM-OLS estimates broadly confirm the principal coefficient directions obtained from the MMQR models, they should not be interpreted as evidence of identical relationships across the entire conditional distribution of the LCF. FM-OLS provides average long-run coefficients rather than quantile-specific estimates. Accordingly, the positive political risk coefficient is more closely aligned with the positive pattern observed in the lower and middle quantiles, whereas the negative economic and financial risk coefficients mainly reflect the relationships identified in the middle and upper quantiles. In particular, FM-OLS does not capture the statistically insignificant economic and financial risk coefficients observed at the lower quantiles or the changes in coefficient magnitude across the conditional distribution. The FM-OLS results therefore confirm the general long-run coefficient directions, while the MMQR estimates provide the distributional evidence underlying these average relationships.

Overall, the FM-OLS estimates provide complementary long-run evidence that is broadly consistent with the principal coefficient directions identified by MMQR. Following the complementary long-run estimation, an additional joint MMQR specification is examined to assess the sensitivity of the baseline results to the simultaneous inclusion of the three risk dimensions.

5.4.3. Sensitivity Analysis: Joint MMQR Specification

To examine whether the results obtained from the separate risk specifications were sensitive to the exclusion of the other risk dimensions, an additional MMQR model was estimated by including political, economic and financial risk simultaneously. The joint specification retained the same log-log functional form, country-specific effects and set of control variables used in the baseline MMQR models; the only difference was that the three risk indicators were included simultaneously rather than separately. This specification was not intended to replace the baseline models, which were designed to compare the three conceptually distinct risk dimensions under an identical empirical framework. Rather, it was used to assess whether the main coefficient patterns remained after controlling for the other risk dimensions simultaneously. To improve the readability of the results, Table 12 reports only the coefficients of the three risk indicators, although all explanatory variables were included in the estimation. The results are presented in Table 12.

Table 12 indicates that the principal findings obtained from the baseline MMQR models remain broadly robust when political, economic and financial risks are included simultaneously in a single specification.

Political risk exhibits a positive and statistically significant association with the LCF throughout the conditional distribution. Its coefficient increases moderately from 0.2262 at q10 to 0.2707 at q90. Notably, the coefficients at q80 and q90, which were statistically insignificant in the baseline specification, become statistically significant in the joint specification. Nevertheless, the coefficient estimates remain within a relatively narrow range across quantiles. The joint results therefore reinforce the main finding that lower political

risk is positively associated with environmental sustainability, even after economic and financial risk are controlled for simultaneously.

Table 12. Joint MMQR estimates.

	lnPR	lnER	lnFR
Location	0.2471 ^a	−0.0181	−0.1081 ^b
Scale	0.0147	−0.0719 ^a	−0.0733 ^a
q10	0.2262 ^a	0.0842	−0.0038
q20	0.2309 ^a	0.0614	−0.0271
q30	0.2357 ^a	0.0377	−0.0512
q40	0.2410 ^a	−0.0121	−0.0773
q50	0.2467 ^a	−0.0157	−0.1057 ^b
q60	0.2530 ^a	−0.0469	−0.1375 ^a
q70	0.2580 ^a	−0.0709 ^c	−0.1619 ^a
q80	0.2647 ^a	−0.1040 ^c	−0.1957 ^a
q90	0.2707 ^a	−0.1334 ^b	−0.2257 ^a

^a $p < 0.01$, ^b $p < 0.05$, ^c $p < 0.10$. Statistical significance is based on heteroskedasticity-robust standard errors computed using the Huber–White sandwich estimator. All baseline control variables and country-specific effects were included in the estimation but some are omitted from the table for brevity.

Financial risk also preserves the general pattern observed in the baseline model. Its coefficient is statistically insignificant at the lower quantiles but becomes negative and statistically significant from q50 onward, with its absolute magnitude increasing steadily toward the upper quantiles. This pattern suggests that the negative association between lower financial risk and the LCF remains concentrated in the middle and upper parts of the conditional LCF distribution.

The economic risk results are comparatively more sensitive to the joint specification. Although the estimated coefficients gradually decline across the conditional distribution and become negative from the middle quantiles onward, statistical significance is observed only at the upper quantiles. Given the relatively strong correlation between economic and financial risk ($r = 0.7814$), the lower statistical precision of the economic risk estimates may reflect the substantial shared variation between the two indicators when they are included simultaneously. Nevertheless, the overall quantile pattern remains consistent with the baseline findings, as the economic risk coefficient becomes increasingly negative toward the upper part of the conditional LCF distribution.

The scale estimates provide additional evidence regarding these distributional patterns. The scale coefficient of political risk remains statistically insignificant, whereas the scale coefficients of economic and financial risk are negative and statistically significant. These results are broadly consistent with the increasingly negative economic and financial risk coefficients observed at higher quantiles.

The remaining explanatory variables, which are omitted from Table 12 for conciseness, retain their expected signs and remain broadly consistent with the baseline MMQR estimates. Income per capita continues to exhibit a negative coefficient, its squared term remains positive, urbanization retains its negative association with the LCF, and renewable energy consumption continues to exhibit a positive association across the conditional distribution.

Overall, the joint specification does not materially alter the principal conclusions of the study. Political risk retains its positive association with the LCF, while the negative financial risk pattern remains particularly stable across the middle and upper quantiles. The economic risk estimates become less precisely identified when the shared variation with financial risk is controlled for, but their general distributional pattern is preserved. The joint model therefore provides complementary evidence supporting the baseline findings,

while the separate specifications continue to offer a clearer comparative assessment of the three conceptually distinct risk dimensions.

6. Discussion and Policy Implications

The empirical findings provide evidence of the factors associated with the load capacity factor in upper–middle-income countries. Overall, the results show that the LCF is related not only to income per capita and the energy structure but also to urbanization and country risk conditions, and these relationships vary across the conditional distribution. Because the research design is observational, the following discussion interprets the estimated coefficients as conditional associations and treats the proposed transmission mechanisms as plausible rather than causal. This distributional heterogeneity also indicates why mean-based estimates alone may conceal relevant differences across lower, middle and upper conditional LCF levels.

First, the results reveal a nonlinear relationship between income per capita and the LCF. The negative coefficient of log income per capita and the positive coefficient of its squared logarithmic term are consistent with a U-shaped income–LCF relationship. This finding is consistent with studies supporting the Load Capacity Curve (LCC) hypothesis for OECD countries, BRICS-T countries, BRICS countries, Asian economies, G-7 and G-8 countries and several country groups, including upper–middle-income economies (Arjun & Mishra, 2025; Ayad & Djedaïet, 2024; Byaro et al., 2024; Guloglu et al., 2023; Imran et al., 2025; Javed et al., 2025; K. A. Khan et al., 2025a; Sarabdeen et al., 2024; W. Wang et al., 2024; Wu et al., 2023; Yıldırım et al., 2024; Yong et al., 2024). Economically, this result suggests that growth may initially increase ecological pressure through industrialization, fossil fuel dependence, the urban infrastructure demand, natural resource use and energy-intensive production. At higher income levels, this adverse relationship may weaken when additional income is accompanied by cleaner technologies, stronger environmental regulation, renewable energy investment and greater environmental awareness.

The quantile-specific estimates provide additional distributional insight. The absolute magnitudes of both the negative lnEG coefficient and the positive squared logarithmic income coefficient generally decline toward the upper quantiles, indicating that the estimated quadratic income–LCF pattern varies across the conditional distribution. However, the marginal association between income per capita and the LCF at any given income level depends jointly on both coefficients. Thus, neither the nonlinear relationship nor the quantile pattern implies that rising income automatically produces environmental improvement. Rather, the environmental implications of higher income may depend on whether it supports a structural transformation toward cleaner energy and more resource-efficient production.

The findings suggest that strategies aimed at raising income per capita may need to be accompanied by measures that improve the environmental composition of economic activity. Policy attention may therefore focus on cleaner production technologies, energy efficiency, renewable energy investment and the regulation of carbon-intensive sectors. Without such complementary changes, rising income may remain associated with greater ecological pressure.

Second, renewable energy consumption is positively associated with the LCF. This positive association is consistent with the view that renewable energy may support environmental sustainability through lower fossil fuel dependence and ecological pressure. The MMQR results further show that the positive marginal association of renewable energy is relatively stronger at the lower quantiles and gradually weakens toward the upper quantiles. This pattern suggests that renewable energy expansion may be particularly relevant for observations characterized by relatively low conditional LCF levels, where the potential environmental gains from replacing fossil fuel-based energy may be greater. The declining

coefficient magnitude toward the upper quantiles does not imply that renewable energy becomes unimportant; rather, it may indicate that additional environmental gains increasingly depend on effective fossil fuel substitution, energy efficiency and supporting technological infrastructure. Since these mechanisms were not directly tested in the present analysis, this interpretation should be considered a plausible explanation rather than a causal conclusion.

The quantile-specific pattern suggests that strengthening the renewable energy transition may be particularly relevant in the lower part of the conditional LCF distribution. However, previous evidence indicates that renewable energy does not generate equivalent environmental gains under all conditions (Altıntaş et al., 2024; Annor et al., 2024; Byaro et al., 2024). Its contribution is likely to be greater when financing, infrastructure and clean technology policies enable renewable sources to replace rather than merely supplement fossil fuel consumption (Anas et al., 2024; Destek et al., 2024; Jahanger et al., 2024; Kirikkaleli & Adebayo, 2024; X. Liu et al., 2025; Pata et al., 2024b).

Third, urbanization is negatively and statistically significantly associated with the LCF across all models and quantiles. This consistent pattern suggests that urban expansion is associated with environmental pressure throughout the conditional LCF distribution in upper-middle-income countries. Urbanization may increase the housing demand, transportation needs, infrastructure pressure, waste generation and energy consumption, while land use change may simultaneously reduce biocapacity. When urban expansion is not accompanied by clean technologies, sustainable infrastructure and effective land use planning, these combined pressures may increase the ecological footprint and weaken the ecological capacity. This interpretation is consistent with studies showing that urbanization is associated with lower environmental quality through the energy demand, transport pressure, land conversion and industrial concentration (Dada et al., 2025; Khalid et al., 2026; Raihan, 2025; Jiang et al., 2024).

The quantile-specific estimates provide additional insight. The magnitude of the negative urbanization coefficient generally increases toward the upper quantiles, suggesting that observations characterized by relatively higher conditional LCF levels are not insulated from the environmental pressures associated with urban expansion. One plausible interpretation is that land conversion, infrastructure development and rising transportation and energy demands may erode the existing environmental advantages in these parts of the distribution. Since these channels were not directly tested in the present analysis, this interpretation should be regarded as a plausible explanation rather than a causal conclusion.

The findings suggest that urbanization should be addressed jointly with land use, transportation, housing and infrastructure planning rather than as a purely demographic process. Policy attention may focus on compact urban development, public transportation, the protection of biologically productive land and low-carbon urban infrastructure (Guloglu et al., 2023; Pata & Ertugrul, 2023; Raihan, 2025; Sevinç et al., 2025; Teng et al., 2024). Integrating energy efficiency and cleaner production criteria into urban and industrial planning may further help to limit the ecological pressures associated with urban expansion.

Fourth, the findings regarding political risk indicate that greater political stability is associated with a higher LCF, particularly at the lower and middle quantiles. Since higher values of the political risk index indicate lower political risk, the positive PR coefficient suggests that improvements in political stability and institutional conditions may be conducive to environmental sustainability. This result is consistent with studies showing that political stability, the rule of law, control of corruption and institutional quality are positively associated with the LCF through policy continuity, regulatory enforcement and environmental governance (Adebayo & Ullah, 2023; Alharbey & Ben-Salha, 2024; Fang et al., 2024; K. A. Khan et al., 2024; Kiliç Depren et al., 2024; Kirikkaleli & Adebayo, 2024; X. Li et al., 2023; X. Q. Sun et al., 2024). One possible explanation for this positive relationship is that political

stability may operate primarily through institutional continuity, regulatory credibility and enforcement capacity. The concentration of statistically significant coefficients in the lower and middle quantiles may indicate that these institutional conditions are particularly relevant for observations characterized by relatively low or moderate conditional LCF levels, where weaknesses in policy continuity and environmental enforcement may constitute more binding constraints on environmental performance.

For observations in the lower and middle quantiles, the results highlight the relevance of policy continuity, regulatory credibility and consistent environmental enforcement. Policy efforts may therefore focus on protecting climate and energy strategies from short-term political cycles and strengthening the implementation and monitoring of environmental regulations (Fu & Blake, 2026; Ni et al., 2022; Xu et al., 2024). The environmental significance of political stability ultimately depends on whether it supports environmental policy and clean energy investment rather than fossil fuel-dependent and resource-intensive development.

Fifth, the economic and financial risk results present a more complex pattern than the political risk findings. While lower political risk is associated with a higher LCF, lower economic and financial risk are associated with lower LCFs, particularly at the middle and upper quantiles. This contrast may reflect the different mechanisms through which the three dimensions of stability are related to environmental sustainability. Political stability may primarily operate through policy continuity, regulatory credibility and enforcement capacity. By contrast, economic stability may facilitate production, consumption and energy demands through improved macroeconomic conditions, while financial stability may ease financing constraints and expand credit and investment. One plausible interpretation is that the upper-middle-income countries in the sample may not have systematically translated the opportunities created by greater economic and financial stability into environmental gains. Although improved macroeconomic and financial conditions can support long-term investment, technological upgrading and renewable energy deployment, they may also expand conventional production, credit, consumption and energy demands. The negative coefficients at the middle and upper quantiles are therefore consistent with the possibility that the expansionary effects of stability outweighed its potential environmental benefits in these parts of the conditional LCF distribution. In other words, the issue may not be economic and financial stability itself but the limited extent to which the opportunities created by stability are directed toward renewable energy, energy efficiency and environmentally responsible investment. Since these transmission channels were not directly tested in the present analysis, this interpretation should be regarded as a plausible explanation rather than a causal conclusion. This interpretation is consistent with studies showing that financial development and economic expansion may reduce the LCF when they stimulate resource-intensive production and energy consumption (Awosusi et al., 2024; Latif & Faridi, 2023; S. Li et al., 2024; Özbay et al., 2024; Pata & Samour, 2023; Zhao et al., 2023).

The concentration of negative associations in the middle and upper quantiles suggests that economic and financial stability alone may be insufficient to support a higher LCF unless the resulting expansion in production, credit and investment is aligned with environmental objectives. Policy attention may therefore focus on green and sustainable finance instruments that incorporate environmental criteria into credit allocation and investment decisions (Anas et al., 2024; Javed et al., 2025; Kirikkaleli & Adebayo, 2024; Kong et al., 2025). Stronger environmental screening, regulatory enforcement and accountability may further help to translate macroeconomic and financial stability into environmental gains (Destek et al., 2024; Latif & Faridi, 2023).

Taken together, the findings indicate that the environmental meaning of stability differs according to both the risk dimension considered and the position within the conditional LCF distribution. Lower political risk is positively associated with the LCF, whereas lower

economic and financial risks are negatively associated with the LCF, mainly at the middle and upper quantiles. Thus, stability alone is insufficient to explain environmental performance; its relationship with the LCF depends on the broader institutional, economic and financial context in which development takes place.

The findings are also relevant to several Sustainable Development Goals. By reflecting the balance between ecological demand and ecological supply, the LCF is closely related to SDGs 12, 13 and 15, while the renewable energy, urbanization and risk results connect the analysis to SDGs 7, 11 and 16. The study therefore highlights the interactions of environmental sustainability with energy, urban development, economic policy, finance and governance.

7. Conclusions

This study examined the associations of political, economic and financial risk, renewable energy consumption, income per capita and urbanization with the load capacity factor (LCF) in 26 upper-middle-income countries over the period 1994–2020. The main contribution lies in comparing three conceptually distinct risk dimensions within a common LCF framework and examining whether their relationships with environmental sustainability vary across the conditional LCF distribution. For this purpose, political, economic and financial risk were estimated in separate specifications using MMQR, while FM-OLS provided complementary evidence of the average long-run relationships, and the joint MMQR specification assessed the sensitivity of the separate risk models.

The findings are consistent with a U-shaped relationship between income per capita and the LCF. Renewable energy consumption is positively associated with the LCF, with a generally stronger relationship at the lower quantiles, whereas urbanization is negatively associated with the LCF throughout the conditional distribution. More importantly, the results show that different forms of stability have different environmental meanings. Lower political risk is associated with a higher LCF, particularly at the lower and middle quantiles, while lower economic and financial risks are associated with lower LCFs, mainly at the middle and upper quantiles. The FM-OLS estimates broadly support the principal coefficient directions identified by MMQR, while the sensitivity analysis indicates that the main political and financial risk patterns remain visible when the three risk dimensions are considered jointly.

These findings do not imply that economic and financial stability are inherently detrimental to environmental sustainability. Rather, they suggest that stability alone may be insufficient to generate environmental gains and that its relationship with the LCF may depend on the broader institutional and structural context in which development takes place. Political stability may support environmental sustainability when it strengthens the continuity and enforcement of environmental policies. Similarly, improved economic and financial conditions may create greater investment and financing opportunities; however, these conditions may not be associated with better environmental outcomes unless such opportunities are directed toward cleaner energy, energy efficiency and less resource-intensive production. Accordingly, the central implication of the study is that the environmental significance of stability depends not only on the reduction of political, economic or financial risk but also on how the institutional and economic opportunities created by greater stability are used.

As with any empirical study, this research has several limitations. First, the observational research design and the estimators employed identify conditional and long-run associations rather than causal effects. Accordingly, the findings should not be interpreted as establishing that changes in the explanatory variables directly cause changes in the LCF, and the possibility of reverse causality, omitted-variable bias and other sources of endogeneity

cannot be completely ruled out. Second, due to data availability, the analysis is limited to 26 of the 54 upper-middle-income economies initially considered. This restriction limits the generalizability of the findings. Moreover, because inclusion in the final sample depended on the availability of complete data, economies with stronger statistical reporting capacity may be relatively better represented, although whether this pattern also reflects broader differences in institutional capacity could not be directly assessed. Third, although the selected variables capture important dimensions associated with the LCF, environmental sustainability is multidimensional, and the models do not directly include potentially relevant factors such as environmental technology, green finance, industrial structure, environmental regulation, energy efficiency and natural resource governance. Fourth, the study covers the period 1994–2020 and therefore does not capture subsequent developments, including the COVID-19 pandemic, geopolitical conflicts and post-2020 energy market shocks. Finally, the political, economic and financial risk indicators are based on expert assessments and aggregate composite scores, which may entail measurement limitations and conceal heterogeneous relationships among their individual subcomponents.

Future research may address these limitations by employing research designs and identification strategies that are better suited to causal inference and can reduce concerns regarding reverse causality, omitted-variable bias and other sources of endogeneity, provided that the relevant identification assumptions can be adequately justified. As the data coverage improves, broader country samples and systematic comparisons between included and excluded economies could be used to assess potential sample selection bias. Future models could also incorporate omitted structural and environmental factors, particularly environmental technology, green finance, industrial structure, environmental regulation, energy efficiency and natural resource governance. Extending the study period beyond 2020 would allow subsequent global, geopolitical and energy market developments to be considered, while disaggregating the composite political, economic and financial risk indices could reveal which individual risk components are most closely associated with the LCF.

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Abbreviations

LCF	Load Capacity Factor
LCC	Load Capacity Curve
MMQR	Method of Moments Quantile Regression
ICRG	International Country Risk Guide

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